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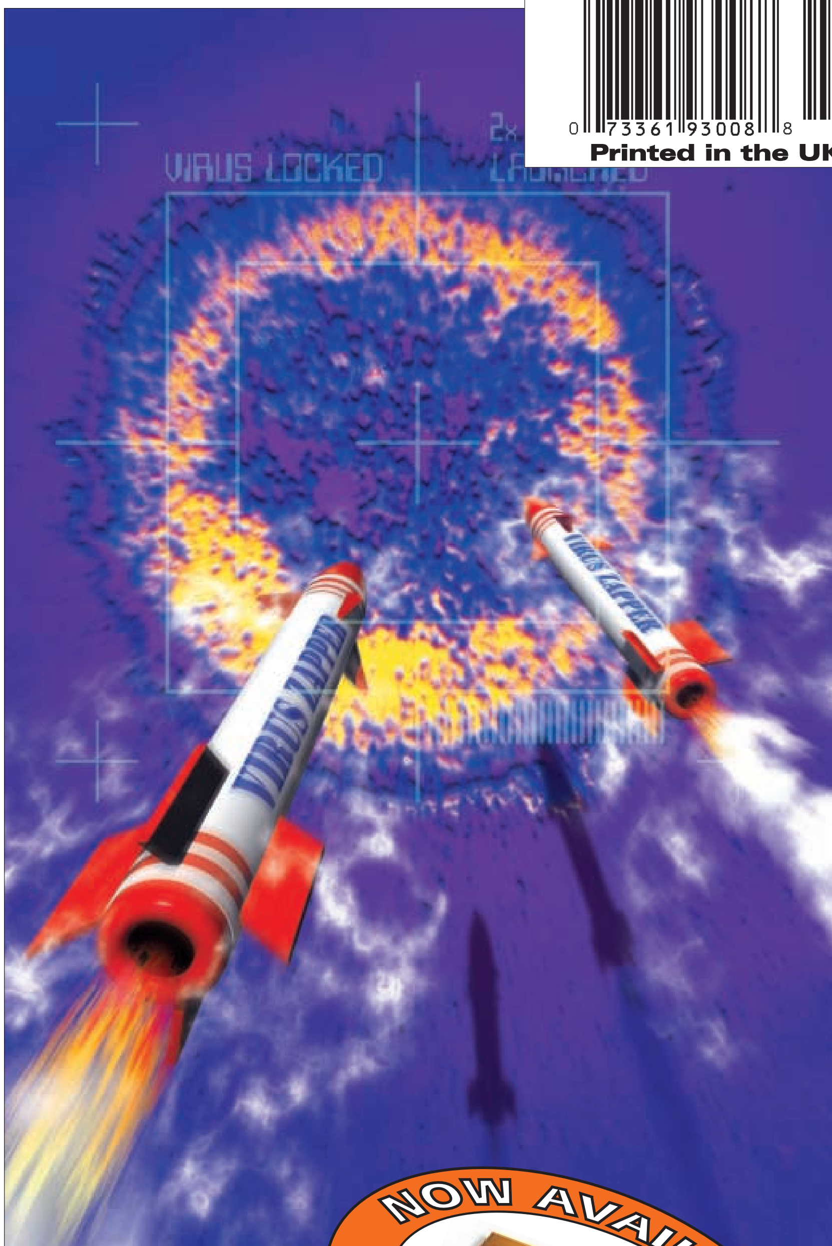

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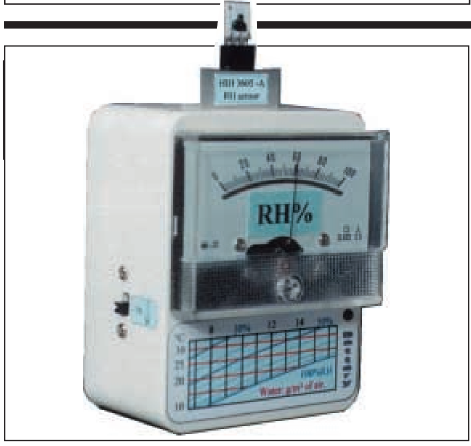

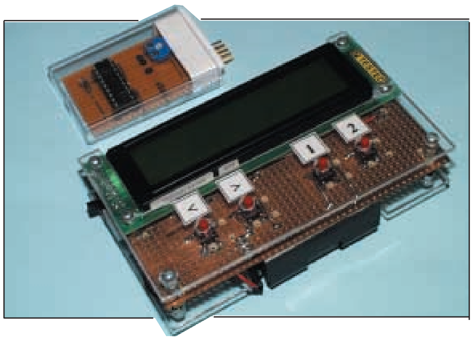

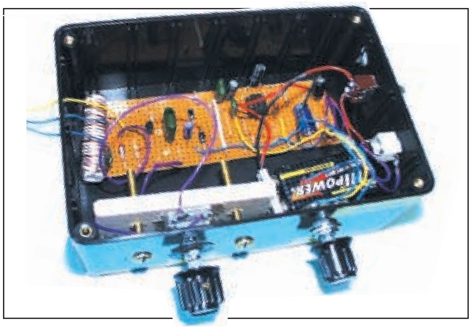

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NEXT MONTH

PIC-CONTROLLED INTRUDER ALARM

This sophisticated multi-zone intruder detection system offers the following deluxe monitoring facilities:

- *alphanumeric liquid crystal display of all functions*
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- *zone entry/exit exit time adjustable, 1 to 99 secs*
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- *keypad selection of control options*
- *mains powered, plus trickle-charged battery back-up*
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- *l.c.d. preview of zone sensor status*
- *system checking via indicator lights without activating the bell*
- *"panic" button always enabled for immediate use*
- *"passive" advice (buzzer) of zone sensor status when required*
- *accepts all conventional types of switched-output commercial sensor*
- *optional slave keypad with separate PIN code for access to selected zone*
- *plus many more features*

ELECTRIC GUITAR TUNER

This guitar tuner design uses a very simple frequency comparison circuit that works just as well whether the input to the comparator is at the fundamental frequency or a harmonic. This avoids the need for any signal processing other than a simple input amplifier.

The display is just a single l.e.d. that flashes at a rate equal to the difference between the guitar's frequency and the correct frequency. Correct tuning is therefore indicated by a steady state from the l.e.d. indicator. The unit is powered from a small 9V battery and it is fully portable.

This project is simple enough to be tackled by a complete beginner at electronic project construction. No test equipment is needed to set up the finished unit, but an accurately tuned instrument or pitch-pipes are needed to provide reference frequencies.

SOLAR CHARGE AND GO

With more and more people "travelling" and using mobile phones, not only to keep in touch with family and friends but also as an item of safety equipment, there comes the need to recharge when miles from the nearest power point or car battery. This solar-operated circuit will charge a nominal 2·4V or 3·6V nickel-cadmium or nickel metal hydride mobile phone battery. It may also be used to power an inexpensive 3V personal cassette player (the type that normally uses two AA size cells). You could listen to music or learn the local language!

FREE GIANT OP.AMP DATA CHART

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But still we get letters, phone calls, faxes and emails from readers who obviously have the magazine but want to know about one of the above services. Sometimes it seems they just want to ask something – anything! We are, of course, happy to help with queries but often it would save everyone some time if readers would please check in the magazine before contacting us. Unfortunately, our time has to be mainly dedicated to producing *EPE*.

ELECTRONIC *EPE*

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MK484 SHORTWAVE RADIO

TOM MERRYFIELD

Hit the shortwave trail with this two chip receiver

ALTHOUGH many a constructors have cut their teeth on building ZN414 radio circuits, the device, sadly no longer in production, now has a first class replacement in the MK484 a.m. radio chip.

The MK484 i.c. is a similarly three-pinned device with a.g.c. (automatic gain control) requiring only a few components to make a high quality tuner with a maximum supply voltage of just 1·8V. But that isn't all! The author was intrigued to see if it performed as well as its predecessor with the popular LM386 audio amplifier i.c. added to make a simple but effective shortwave radio project with loudspeaker output.

CIRCUIT DESCRIPTION

The results were quite surprising and the full circuit diagram for the MK484 Shortwave Radio is shown in Fig.1.

As with f.e.t.s, the circuit's high input impedance (several megohms!) is exploited to receive shortwave frequencies up to several megahertz (MHz), so long as the tuned circuit has negligible losses, thereby maintaining good selectivity.

The tuned circuit of the receiver is formed by L1, wound from 24 s.w.g. enamelled copper wire, and variable capacitor VC1. (For Cx and the aerial coil L2, see later.) Resistor R1 is needed to bias IC1, with capacitor C1 ensuring stability. As with other "front end'' tuner components these should be soldered close to IC1, with coil L1 and VC1 leads to the circuit board kept as short as possible.

Resistor R3 and capacitor C2 play an important role in setting the optimum gain for the MK484. In theory, the gain could be increased until instability results but there would be a loss in audio quality – i.e., more noise – well before this point. Hence the selection of R3 and C2 values.

Given that the maximum allowable supply to the MK484 should not exceed 1·8V, in conjunction with resistor R4, diodes D1 and D2 stabilise the voltage at about 1·5V. Due to the voltage drop across resistor R3, this falls to between 1·3V and 1·4V; a typically safe working voltage for the radio chip.

Capacitor C3 is needed to block d.c. getting through to the following audio stage, whilst coupling IC1's output signal to the LM386 audio amplifier IC2, via Volume conntrol VR1, at pin 3. Note also the bypass capacitor C4 preventing any stray r.f. from being connected to IC2.

From this point onwards the circuit is fairly typical with capacitor C5 setting the gain of IC2 and pins 2, 4 and 7 tied to ground, the latter via capacitor C6.

The inclusion of R6, C9, R5 and C7 prevents instability, thereby avoiding distortion in the output. In fact, the value of resistor R5 could be raised slightly higher to 18 ohms.

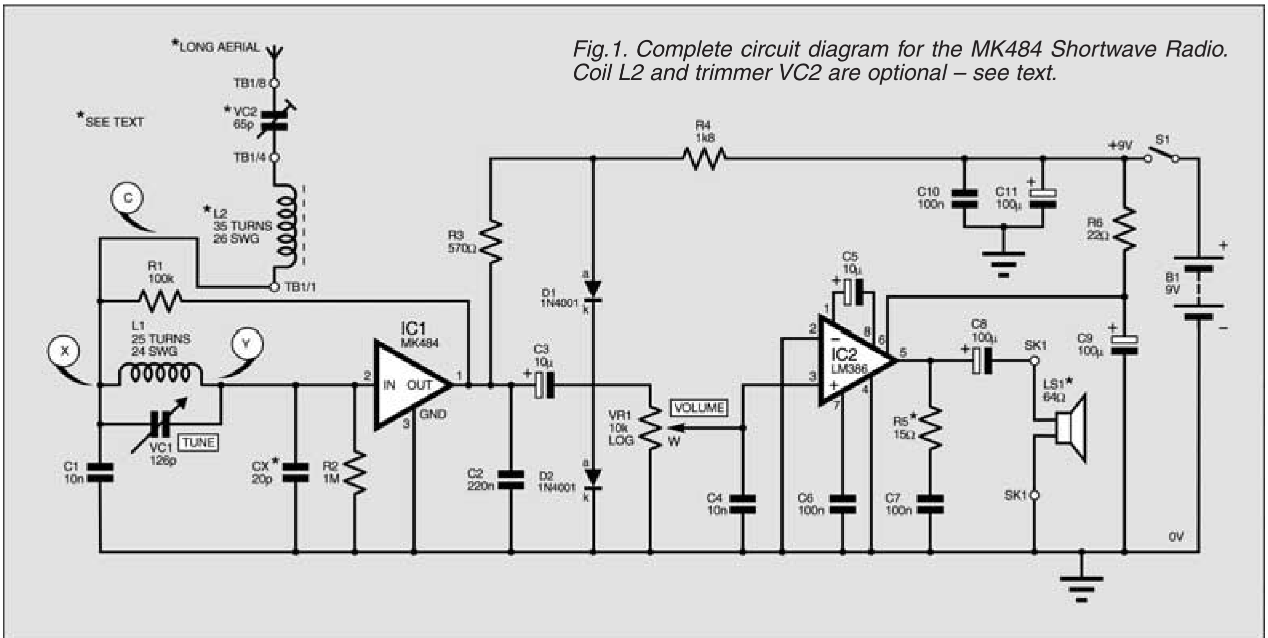


Fig.1. Complete circuit diagram for the MK484 Shortwave Radio. Coil L2 and trimmer VC2 are optional – see text.

With the output impedance being fairly low, a 64 ohm speaker gives a strong and even output but should be placed away from the tuned circuit area to avoid spurious feedback. For weaker signals however, Walkman type headphones can be used.

Q FACTOR AND AERIAL COIL

One point to bear in mind is that beyond 4MHz, losses in the tuned circuit heavily affect the selectivity. That is, the ability of a receiver to magnify a selected signal and reject others without an appreciable loss in gain.

In trials, the main coil L1 being loosely wound from 24 s.w.g. enamelled wire at 25 turns provided a suitable *Q* factor whilst still giving a broad enough tuning range.

As with most high gain devices at the front end, overloading tends to be a problem. This was certainly clear with the prototype. An ATU (Antenna Tuning Unit) would be ideal here in terms of matching the impedance of the aerial system and thus the signal to that of the receiver's input.

Failing that, an adequate measure is to connect up a long aerial lead via an aerial coil (L2) wound on a length of ferrite rod, and connected to the junction of R1, L1/VC1, via lead *C* (see Fig.1 and Fig.2.) This, in effect, provides additional tuning by sliding the aerial coil along the ferrite rod.

The long aerial itself can be any thin p.v.c. insulated connecting wire of 10 metres or so mounted as high as possible. For the most part this gives adequate results.

GETTING IN TRIM

In the prototype, a trimmer capacitor, VC2, was wired to the aerial circuit in series with the aerial coil L2 to give additional selectivity. With appropriate adjustment, this proved very effective in selecting individual signals from the crowded shortwave bands.

However, one precaution has to be observed; it is important to keep the aerial circuit and thus the aerial coil L2 well away from the main coil L1 and the receiver's input. Otherwise the signal can in effect bypass or "leapfrog" ahead instead of passing through the aerial coil!

Although the prototype was built on stripboard, a terminal block is ideal for wiring up the aerial coil L2 and trimmer capacitor VC2 and divorcing it from the tuned input circuit (Fig.2).

As a rough and ready filter, polystyrene capacitor Cx is needed to subdue stronger signals. Although a 20pF capacitor has been quoted, any value from 20pF to 50pF can be tried. In case a polystyrene isn't available, a ceramic-dipped or multi-layered capacitor also works well.

COIL WINDING

Some readers may be surprised at home-made coils being used in the receiver as opposed to commercial types. In trials, these proved far more effective than the latter whilst being simple to make and inexpensive.

Unfortunately, a badly constructed coil can impinge on the performance by inhibiting the *Q* factor. On the other hand this can be easily avoided, the key being a good former and plenty of patience.

The former on which coil turns are wound can be a sheet of thin cardboard or gum paper about 40mm by 35mm wide rolled into a tube. Its diameter should be slightly larger than that of any ferrite rod/slab used so it can freely slide up and down. It is, therefore, a good idea to make this check before proceeding further.

It is also important to apply sticky tape *inside* as well as out. This keeps the former robust enough to withstand compressive stresses.

As for winding the turns, any difficulties can be avoided by handling the wire tactfully so it doesn't tie itself up in to knots. A good start is essential by securing the first few turns with insulation tape to prevent them from unwinding.

For the main coil L1, loosely wind 25 turns of 24 s.w.g. enamelled copper wire onto the carboard former, making sure there is a gap between most turns. Leaving short lengths at the start and finish of the coil for later attachment to the circuit board. Once completed, fasten the start and end windings with adhesive insulation tape and scrape the enamel coating off the end of the leads.

The aerial coil L2 should be made up of 35 turns of 26 s.w.g. enamelled wire more tightly wound with most turns touching. Once complete, check for any weak points and seal over with another applicationation of tape or wax. The enamel coating for the "tailends" can be gently scraped off using sand-paper or emery cloth.

CONSTRUCTION

Despite employing quite a few capacitors, the receiver's simplicity means building it should not be too complicated a task.

COMPONENTS

Approx. Cost Guidance Only £18 excl. speaker & case

See SHOP TALK page

Resistors

R1	100k
R2	1M
R3	570Ω
R4	1k8
R5	15Ω
R6	22Ω

All 0·25W 5% carbon film

Potentiometers

VR1	10k min. rotary carbon, log.

Capacitors

C1, C4	10n mylar poly. (2 off)
C2	220n mylar polyester
C3, C5	10µ radial elect. 25V (2 off)
C6, C7	100n disc ceramic, 5mm pitch (2 off)
C8, C11	100µ radial elect. 25V (2 off)
C9	100µ axial elect. 25V
C10	100n mylar polyester
Cx	20p axial polystyrene (see text)
VC1	126p min. a.m./f.m. tuning capacitor (ZN414 type)
VC2	5·5p to 65p min. trimmer

Semiconductors

D1, D2	1N4001 1A 50V rect. diode (2 off)
IC1	MK484 a.m. radio i.c.
IC2	LM386 low voltage audio amp.

Miscellaneous

LS1	64 ohm 0·3W loudspeaker (see text)
SK1	3·5mm mono jack socket
S1	s.p.s.t. toggle switch
TB1	8-way screw terminal block
L1, L2	tuning coils (see text)

Stripboard, 0·1in. matrix, size 50 holes by 15 strips; plastic case, size approx. 160mm x 90mm x 55mm; 24 s.w.g. and 26 s.w.g. enamelled wire for coils; ferrite rod/slab; 8-pin d.i.l. socket; 9V battery, with PP3 type clips; long aerial wire (10m p.v.c. covered connecting wire); plastic knob, 16mm skirted; 12·5mm long hexagonal spacer; M2·5 x 15mm screw; M4 x 30mm stud with nut (2 off); adhesive strips and card for aerial formers; solder pins; solder etc.

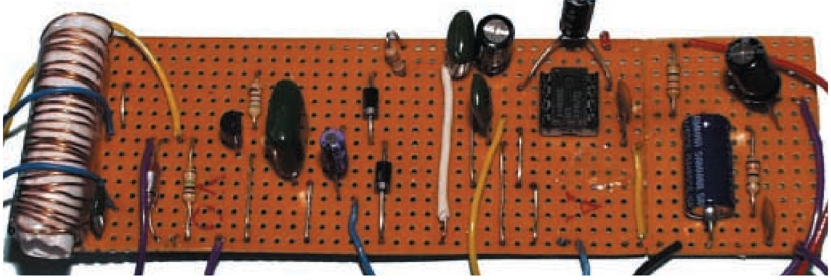
The prototype was built on a piece of stripboard measuring 50 holes by 15 copper tracks.

The topside component layout, interwiring and details of the breaks required in the underside copper tracks are shown in Fig.2. Commence construction by making all the necessary copper track breaks and inserting all the link wires (9 off).

This should be followed by inserting the resistors, capacitors, diodes and the two i.c.s. Care should, of course, be taken to ensure that diodes and electrolytic capacitors are inserted the correct way round. Wiring-up the aerial coils, volume control and tuning capacitor is carried out later when assembling the circuit board into a case.

Because the MK484 i.c. can be damaged by excessive heat, some form of heatsink is necessary during soldering. For instance, holding the device with metal tweezers to conduct the heat away whilst soldering it in; or attaching a croc-clip. An i.c. holder should be used for the LM386, IC2.

Once the soldering is complete, check for dry joints and tiny splashes of solder between tracks – the latter can be very easily missed, contributing to the "invisible short circuit" phenomenon. Also, double-check that all polarised components are correctly wired on the circuit board.



Prototype stripboard component layout.

As stated previously, the aerial coil L2 and trimmer capacitor VC2 should not be soldered directly to the board, but instead are wired via an 8-way terminal block. To help reduce losses at higher frequencies, keep the tuned circuit leads as short as possible.

TESTING

Although designed for shortwave use, the receiver can be easily tested in medium wave mode to see if everything works.

A pre-wound MW coil or one made from 30s.w.g. wire of 50 to 60 turns on a ferrite rod acts as the main coil for receiving MW frequencies. Also, no aerial, aerial coil or trimmer is required. If all is well, a strong and even output should be heard from the speaker or headphones at a half turn of the Volume control VR1.

CASING IT UP

Bearing in mind the prototype was used for the reception of high frequency bands with Walkman type headphones, the unit was cased in a box approximately 160mm × 95mm × 55mm high, without the speaker.

This kept things simple by using a 3·5mm mono socket for either headphone or a loudspeaker output. If preferred, a speaker could be mounted in a bigger case with a series of perforations over the speaker section.

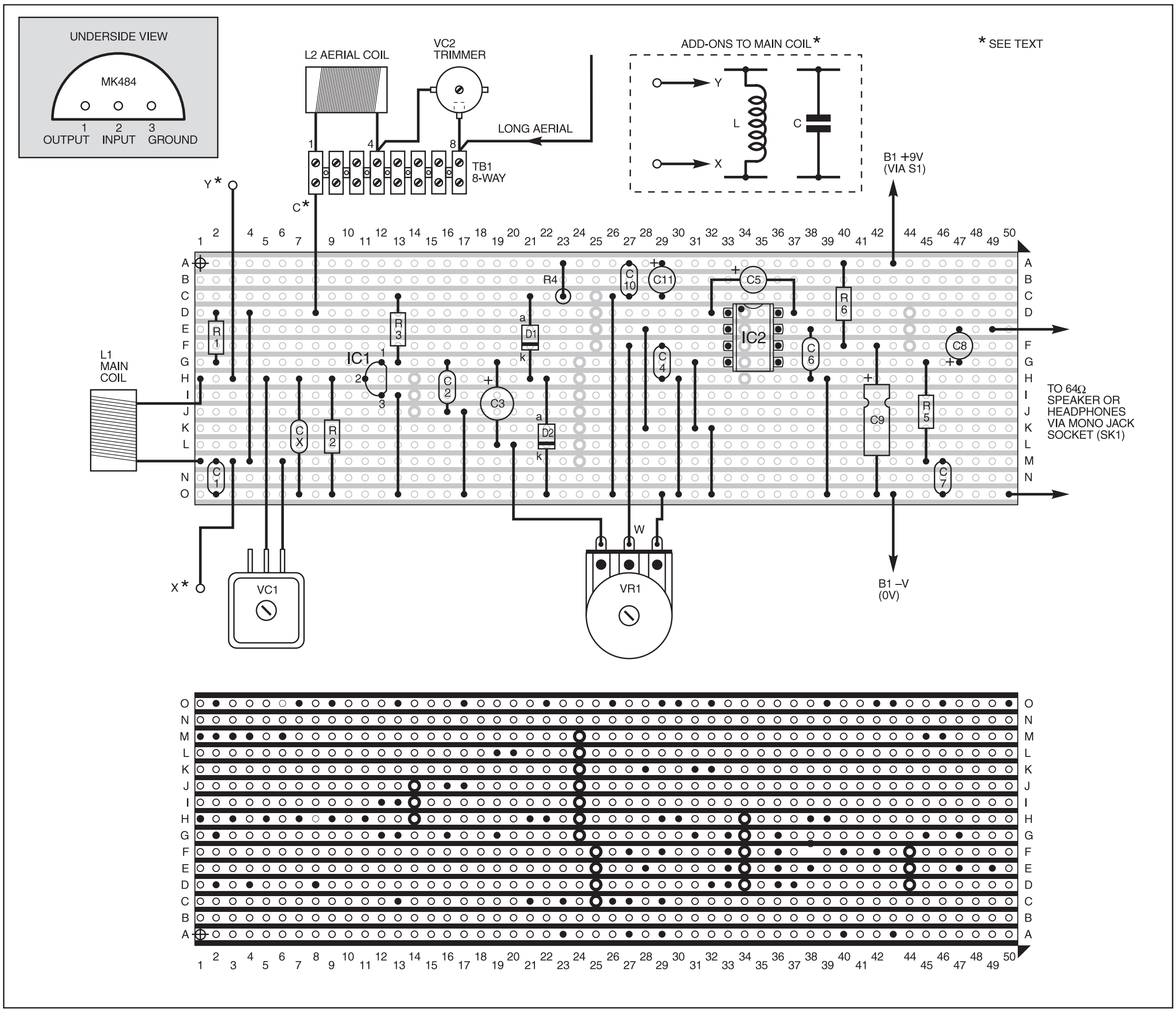


Fig.2. Stripboard component layout, interwiring and details of breaks required in the underside copper tracks. Pinout details (underside) for the MK484 radio chip are shown inset top left. Leads X and Y are for attaching additional tuning components.

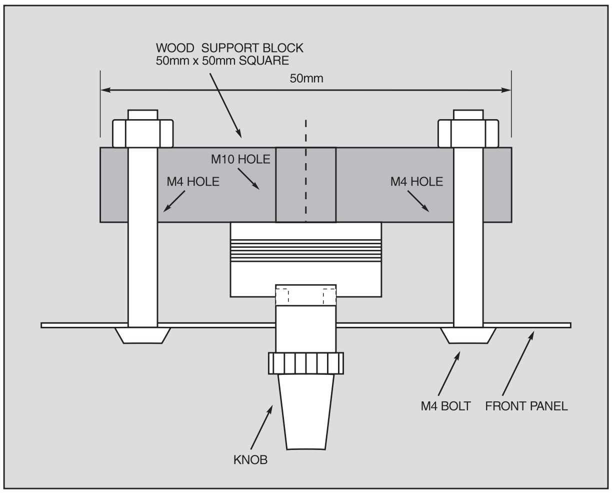
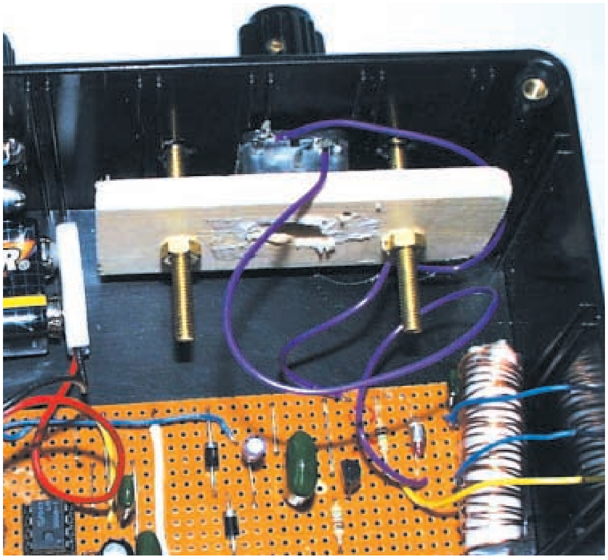


Fig.3. Suggested method of fitting the variable tuning capacitor VC1 to the front panel.



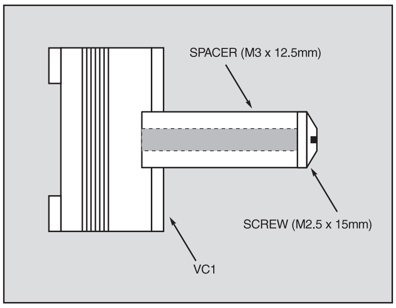


Fig.4. Lengthening the tuning capacitor spindle.

In terms of varying the frequency range, this can be achieved by adding a second coil or low value polystyrene capacitor in parallel with the main coil. Hence the leads *X* and *Y* in Fig.2. Given that the main coil L1 is soldered in-circuit, the "additions" can be wired up using a terminal block; as with the aerial circuit this is placed outside of the case. The circuit board and battery were simply affixed to the bottom panel of the case using adhesive pads.

TUNING CAPACITOR

More challenging is mounting the standard a.m. variable capacitor (VC1) securely to the panel. Basically, this isn't easy because of the tuner's dimensions, so a bit of improvising is needed.

As Fig.3 shows, a square offcut of thin wood or plastic measuring around 50mm × 50mm acts as a support to keep VC1 in place relative to the panel via M4 studs after drilling holes.

The problem of lengthening VC1's shaft is solved by using a hexagon spacer secured with an M2·5 screw of approp- riate length, see Fig.4. Care is needed here not to drive the screw too far into the capacitor, this risks damaging the vanes. A knob can then be attached, preferably with an adjustable grub screw fixing.

RESULTS

The prototype picked up many stations from all over Europe including Sweden and Denmark and several American religious broadcasts on the 41 metre band. The latter signals, however, required fine-tuning via the trimmer using a small screwdriver.

For higher frequencies, including the 25 metre band, little or no adjustment of the aerial coil may be needed. This includes broadcasts from China and many arabic stations including the United Arab Emirates.

Depending on atmospheric conditions and propagational effects, some fading of the signal is likely to occur at these frequencies. Of course, this happens with more complex receivers but to a lesser degree due to better signal processing and more stages.

That being said, Radio Korea, Turkey and Egypt were received loud and clear. Generally, the best time to try the h.f. bands is during the evenings when propagation conditions are better.

For those who would like to experiment, using different coils or varying the turns of the main coil always brings interesting results.

With practised intuition, plenty of signals can be tuned in, making the MK484 radio chip an impressive replacement for the ZN414. □

The completed prototype MK484 Shortwave Radio.

New Technology Update

Superconducting transistors known as quatratran devices have evolved from research into particle detection in astronomy. Ian Poole reports.

SUPERCONDUCTORS have been known for many years. Their unusual attribute of having zero resistance seems almost to go against the laws of physics. Generally they are associated with high current machines and electromagnets.

However, they are equally applicable to smaller current electronic circuits where they can bring significant benefits. A further advantage is that although superconductors would only operate at very low temperatures, originally within a few degrees of absolute zero, many new materials are being developed that superconduct at much higher temperatures.

In a new development a three-terminal device with transistor-like properties has been developed by Emeritus Physics Fellow Norman Booth at Oxford University in the UK in collaboration with a group in Naples, Italy.

Their super-conducting device, called a "quasi-particle trapping device" or quatratran (QTT), behaves in a very similar fashion to a transistor. It is anticipated that this device will be used for research projects, particularly in close proximity to arrays of highly sensitive superconducting sensors and detectors that are being used far more widely in astronomy, X-ray micro-analysis and in mass spectrometry applications. As a further advantage, the new quatratrans can be fabricated so that they act as radiation detectors, as well as providing high degrees of amplification.

The new device is particularly convenient to use because it operates well at the very low temperatures required for this work. Conventional semiconductor transistors do not operate well at these temperatures and dissipate a large amount of heat that is difficult to remove efficiently so that the overall temperature of the assembly does not rise,

What are Superconductors?

To understand how superconductors work it is necessary to look at a normal conductor. The nuclei in a normal conducting material are arranged in a regular lattice. They are surrounded by electrons that have escaped from their atoms and are free to move around the lattice. When an electric field is applied across the lattice the electrons are forced to move under the influence of this field. However, the electron movement is hindered by the nuclei and the impurities in the conductor. This causes the electrons to scatter and not flow in an orderly fashion, instead the flow is more random. This impedes the flow of the electrons and gives rise to resistance.

In the case of a superconductor there is an interaction between the nuclei and electrons but in this case the effect results in electrons being able to flow unimpeded through the lattice. What happens is that as one electron flows through the lattice it distorts it. When a second electron approaches the first, it is attracted by the greater density of the positive charge where the nuclei have been pulled together. This effect overcomes the repulsive force that would normally exist between two electrons and they travel together as a pair known as a Cooper pair. These pass through the lattice with no obstruction and as a result there is no resistance.

As the temperature increases the nuclei start to vibrate more and eventually a point is reached where the Cooper pairs start to break up and the material rapidly reverts to its normal state, along with the associated resistance. This effect can also occur if the level of current becomes too high. This is known as the critical current.

Other Properties

There are a number of other properties associated with superconducting states. One of these is a property known as diamagnetism where no magnetic field exists within the conductor. Currents are set up on the surface of the conductor, creating a field that is equal and opposite to the applied field.

A further effect is related to the quantum tunnelling. If two superconductors are separated by an insulating layer between ten and twenty Angstroms thick it is found that two electrons can tunnel through it with no resistance. The effect is known as the Josephson effect and the device is known as a Josephson junction. The device can be used in switching applications because if the junction is placed in a magnetic field the critical current is reduced. The switching action occurs very fast enabling it to be used in applications where other switches could not be used as effectively.

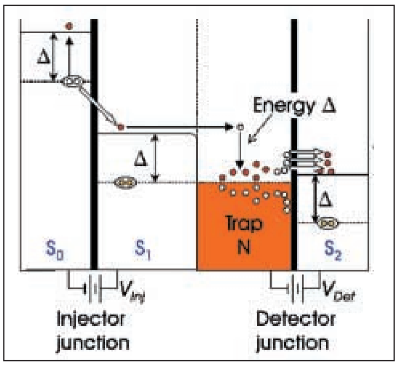


Fig.1. Energy diagram of quatratran operation. The films S0, S1 and S2 are superconducting and N is a normal metal. Quasi-particles injected into the intermediate electrode give up their energy D to heat the electrons in the normal metal. This increases the current through the detector junction.

Transistor Developments

The quatratran device grew out of Booth's work in developing a solar neutrino detector using superconducting principles. The device can be thought of as a three-terminal superconducting transistor. It possesses features such as voltage and current gain, isolation between output and input, impedance compatibility with other devices, low power dissipation, high speed, and the possibility of being easy to manufacture.

Electronic signals are amplified by applying a voltage or current to the injector electrode that consists of a thin film superconductor. The intermediate electrode that consists of a bi-layer of superconductor and a normal metal constitutes the area where the amplification is provided.

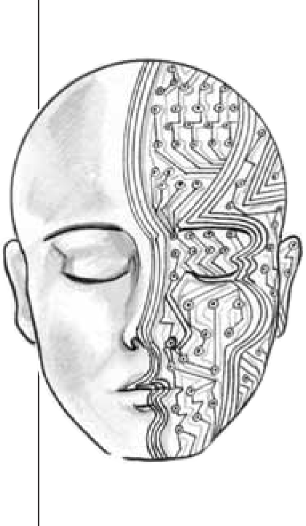
In operation quasi-particles are injected into the intermediate electrode giving up their energy to heat the electrons in the normal metal. In turn this increases the current through the detector junction. As a result amplification is obtained when an electrical signal (which may be either a voltage or current) is applied to the injector electrode. Current gains anywhere between 70 and 1000 have been measured, demonstrating that the device provides some very useful levels of gain.

It is also found that an output signal can be produced from the device when an electromagnetic wave passes through it. When this occurs the signal passes through the transparent substrate and is then absorbed by the injector electrode. In this way it can detect electromagnetic signals – an important feature of the device that enables it to be used in many more applications.

A unique and interesting feature of the device is that it is almost polarity insensitive. It can be used as an equivalent of either a *pnp* or *npn* transistor, simply by reversing the polarities of the power supplies.

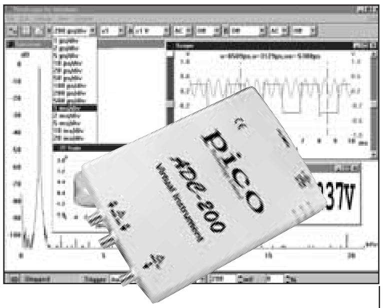
Future

Two further devices can also be fabricated by reversing polarities within the structure. The development team under Booth believe that this opens the door to possibilities of making complex devices using large scale integration techniques. Applications for these devices may include cryogenic particle and radiation detection systems.



INGENUITY UNLIMITED

Our regular round-up of readers' own circuits. We pay between £10 and £50 for all material published, depending on length and technical merit. We're looking for novel applications and circuit designs, not simply mechanical, electrical or software ideas. Ideas *must be the reader's own work* and **must not have been submitted for publication elsewhere.** The circuits shown have NOT been proven by us. *Ingenuity Unlimited* is open to ALL abilities, but items for consideration in this column should be typed or word-processed, with a brief circuit description (between 100 and 500 words maximum) and full circuit diagram showing all relevant component values. **Please draw all circuit schematics as clearly as possible.** Send your circuit ideas to: Alan Winstanley, *Ingenuity Unlimited,* Wimborne Publishing Ltd., 408 Wimborne Road East, Ferndown Dorset BH22 9ND. (We **do not** accept submissions for *IU* via E-mail.)
Your ideas could earn you some cash **and a prize!**



WIN A PICO PC BASED OSCILLOSCOPE WORTH £586

- 100MS/s Dual Channel Storage Oscilloscope
- 50MHz Spectrum Analyser
- Multimeter • Frequency Meter
- Signal Generator

If you have a novel circuit idea which would be of use to other readers then a Pico Technology PC based oscilloscope could be yours.
Every 12 months, Pico Technology will be awarding an ADC200-100 digital storage oscilloscope for the best IU submission. In addition, a DrDAQ Data Logger/Scope worth £69 will be presented to the runner up.

Lightning Detector – Ahead in the Clouds

THE circuit diagram of Fig.1 is a very sensitive static electricity detector that can provide an early warning of approaching storms from inter-cloud discharge well before an earth-to-sky return strike takes place. An aerial (antenna) formed of a short length of wire detects storms within a two mile radius.

The circuit emits an audible warning tone from a piezo buzzer, or flashes an l.e.d. for each discharge detected, giving you advance warning of impending storms so that precautions may be observed, such as unplugging modems, switching off computers and so forth.

The primary feature is the circuit's ability to be set close to self-oscillation, with its relaxation optimised via the bias resistor values shown in the circuit diagram. The oscillator is d.c. coupled and feedback is routed through the collector (c) of transistor TR1 to the base (b) of TR2, while the overall loop gain is set with the multiturn (12, 18 or 22) preset VR1.

Capacitor C3 sets the fixed phase at the emitter (e) of TR2, and at the wiper of VR1 capacitor C2 increments the phase shift for oscillation to occur. *(Any similar small signal high-gain transistor can probably be used, e.g. a BC548C – ARW)*

The collector of TR2 outputs a 42kHz sinewave once triggered, and is coupled by capacitor C4 to the base of TR3. Diode D1 rectifies the positive-going phase of the oscillator, to bias TR3 on and output a d.c. voltage at TR3 emitter. This drives WD1, a self-contained piezo-electric sounder. A pulsed l.e.d. D2 can be added as an option for a visual indication if required.

Setting Up

To set the circuit up, adjust preset VR1 for oscillation by monitoring test point TP1, which should be at roughly 7V peak-to-peak. Test point TP2 should be at +6V d.c. Now readjust VR1 back slightly to stop oscillation; use a screwdriver to touch the aerial-side of C1 several times; the alarm should sound for 1 or 2 seconds then stop. If it continues, make a very small adjustment back, and recheck. The other method is to electrostatically charge a plastic ruler, and then draw your finger close to discharge, about two metres away from the aerial.

Powered from a 9V battery, the Lightning Detector circuit consumes about 600μA in standby. Powered continuously it could provide a good year of uninterrupted monitoring.

When sounding the alarm, the current will rise to 4mA depending on the low current sounder WD1. A minimum 3V device is required for a good output level, and it will produce a "pinging" alarm to warn in real time of any electrostatic pulse activity.

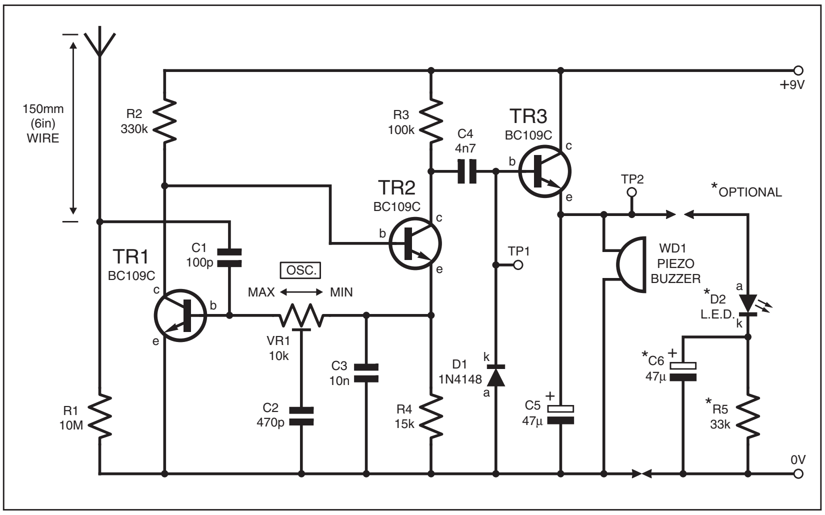


Fig.1. Circuit diagram for the Lightning Detector. Note that preset VR1 should be a cermet multiturn type.

Brian M. Lucas,
St Helier, Jersey,
Channel Islands.

Dog and Cat Scarer

– Buzz Off

THE circuit diagram of Fig.2 is a high output ultrasonic transmitter which was primarily intended to act as a dog and cat scarer, which can be used by individuals to act as a deterrent against some animals. It should *not* be relied upon as a defence against aggressive dogs but it may help distract them or encourage them to go away.

The circuit uses a standard 555 timer IC1 set up as an oscillator using a single *RC* network to give a 40kHz square wave with an equal mark/space ratio. This frequency is above the hearing threshold for humans, but is known to be an irritating frequency for dogs and cats.

Since the maximum current that a 555 timer can supply is 200mA an amplifier stage was required so a high-power H-bridge network was devised, formed by the four transistors TR1 to TR4. A second 555 timer IC2 forms a buffer amplifier that feeds one input of the H-bridge driver, with an inverted waveform to that of IC1 output being fed to the opposite input of the H-bridge.

This means that conduction occurs through the complementary pairs of TR1/TR4 and TR2/TR3 on alternate marks and spaces, effectively doubling the voltage across the ultrasonic transducer, LS1. This is optimised to generate a high output at ultrasonic frequencies.

This configuration was tested by decreasing the frequency of the oscillator to an audible level and replacing the ultrasonic transducer with a loudspeaker; the results were astounding. If the circuit was fed by a bench power supply rather than a battery that restricts the available current, the output reached 110dB with 4A running through the speaker, which is plenty loud enough!

The Dog and Cat Scarer was activated using a normally open push switch S1 to control the current consumption, but many forms of automatic switching could be used such as pressure sensitive mats, light beams or PIR sensors. Thus it could be utilised as part of a dog or cat deterrent system to help prevent unwanted damage to gardens or flowerbeds, or a battery powered version can be carried for portable use. Consider also using a lead-acid battery if desired, and a single chip version could be built using the 556 dual timer i.c. to save space and improve battery life.

D. Stringwell, Scunthorpe, North Lincs.

PICO PRIZEWINNERS

Once again it's time for us to consider our prizewinners, three lucky *Ingenuity Unlimited* contributors each receiving valuable prizes of Pico PC-based Oscilloscopes generously donated to *Everyday Practical Electronics* by PICO Technology Ltd (**www.picotech.com**). Our thanks as always to Pico for their magnanimous support in keeping alive the spirit of "ingenious" circuit design and for generally promoting an interest in exploring the fascinating world of electronics.

All the contributions published between August 2001 and February 2002 were carefully considered by Editor Mike Kenward and host Alan Winstanley for originality and technical merit, appropriateness and completeness. As always, the overall presentation was used as a tie-breaker. The finalists each had their own particular merits making the judges' decision a very tough one!

FIRST PRIZE: *L.E.D. DYNAMO TORCH* by Alan Bradley (Feb 2002), who wins a superb PC-based Pico ADC200-50 Dual-Channel Storage Oscilloscope. The circuit was an interesting application of high brightness l.e.d.s coupled to a dynamo generator, to produce a self-powered flashlight that evolved through methodical experimentation. We are especially pleased to award first prize to a previous Pico runner-up – Alan won a Pico ADC-40 in the October 1998 issue.

RUNNERS-UP: *Precision UV Timer* by Ian Hill (Jan 2002), who wins a PICO ADC-40 PC-based oscilloscope. This was an interesting timer circuit to help produce consistent results with UV exposures, using the mains sinewave to provide an accurate clock signal.

Wein Bridge Audio Generator by Paul Fellingham (Sept 2001), who wins a PICO ADC-40 PC-based oscilloscope. A thoroughly developed audio oscillator using an a.g.c. circuit instead of an expensive thermistor to provide stability.

Congratulations to all PICO prizewinners. Readers, how is your ingenuity? If you have an electronic circuit idea that uses some degree of novelty or "lateral thinking", or you have a circuit tip you would like to share with readers, then why not submit it for possible publication in *Ingenuity Unlimited?* We pay between £10-£50 for each article published and, of course, there's a chance to win a Pico PC-based Oscilloscope as well! We cannot accept items by email, and all articles must be sent by letter post to the Editorial address.

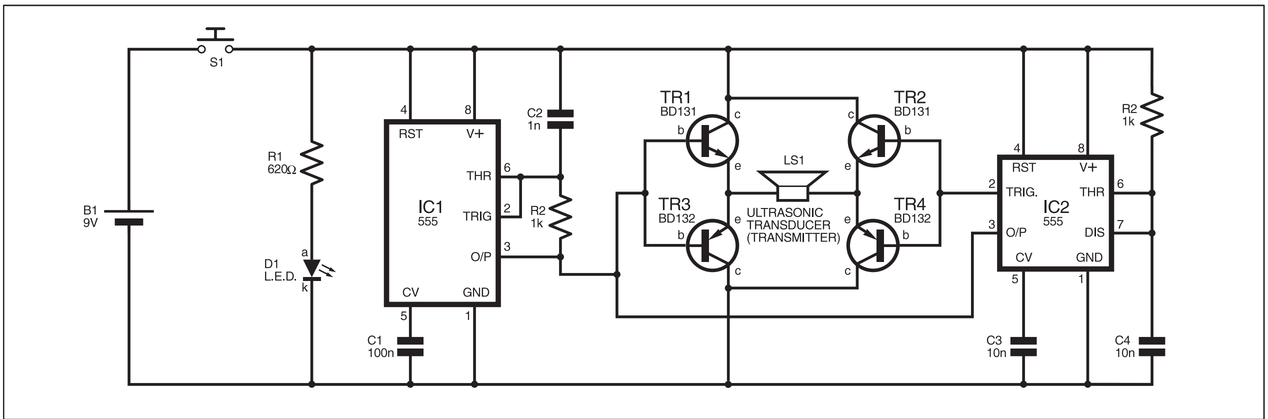


Fig.2. Circuit diagram for a harmless Dog and Cat Scarer.

News . . .

A roundup of the latest Everyday News from the world of electronics

CD COPYING LEGALITY CHALLENGED

There is a confusion in law about the right of CD producers to prevent their CDs from being copied for individual use. Barry Fox reports.

RECORD giant BMG is the first record company in the world to use copy-protection on widely released chart CDs; Natalie Imbruglia's *White Lilies Island* and Five's *Greatest Hits.* Some customers have complained about the unwelcome side effect that the CD only plays in low fidelity on a PC. Although the sleeves and artwork do not refer to copy protection, they do credit a system called Cactus Data Shield from Midbar of Israel. Midbar confirms that the technology used to modify PC playback is covered by international patent application WO 01/80546.

The CD is a "multi-session" disc of a type normally used to let audio and computer data share the same disc. The data and audio are recorded at physically different positions, and the ROM drive in a PC goes first to the data area. On the Imbruglia and Five CDs the data is actually music in heavily compressed form, encrypted so that a PC can only read it with the help of authorised software which is also stored in the data area. The encrypted music cannot be copied by normal PC software. But innocent listeners get only heavily compressed sound.

Although BMG claims that the number of complaints has been "very low", and orchestrated by anti-protection lobbyists, the record company has now backed down on the experiment and new versions of the two discs are being pressed without copy-protection. The tell-tale signs are the reference to Midbar/Cactus on the rear of the artwork and a clear band on the playing surface of the disc which separates the music and data sections.

Congressional Intervention

In the US, Universal's new compilation CD of Fast and Furious rock music is similarly copy-protected but clearly marked with consumer warnings.

But this has not pacified the Congressional Internet Caucus Committee, a public interest group which works to educate Congress and the public on information technology. The Committee is warning the music industry that selling CDs which prevent or inhibit home recording may violate the Audio Home Recording Act (AHRA) of 1992. The AHRA levies a royalty of 2 per cent on the price of recording equipment and 3 per cent on recording media such as tapes and discs. Well over $5 million a year is now collected.

Co-Chairman Rick Boucher has now asked the music industry's main trade bodies, the Recording Industry Association of America and International Federation of the Phonographic Industry, to justify taking money from consumers in return for the right to copy, while using technology to try and prevent copying.

Speaking also for the IFPI, Hilary Rosen, President and CEO of the RIAA, says:

"Copy-protection is not new to the entertainment industry – most movies and videogames sold today have some form of protection. The recording industry is taking steps to get 'in tune' (with) the right balance between preventing wholesale copying and uploading to the Internet, while still allowing some copying onto hard drives or CD-Rs for personal use. Fans may rest assured that these companies' first priority will remain the listening experience."

Martin Dalgleish, of British hifi company Linn, warns that finding the right technology is getting harder all the time because hardware manufacturers are finding it increasingly difficult to obtain good quality CD drive components. So they often build computer ROM drives into their consumer CD and DVD players; and some of the copy-protection systems are designed to interfere with ROM drive playback.

Changing the Rules

"The recent non-CDs from BMG change the rules in a totally unpredictable way. There is no published specification and therefore it is impossible for Linn or any other company to predict the playability of these discs. The CD players we make all react in different ways."

The UK is the only country in Europe where it remains illegal to copy one's own CD for personal use. Like the US, most major European states levy a royalty on recording media. But lawyers for the IFPI's Head Office in London insist there is no link in law between paying a royalty and the right to make a copy.

"So using copy-protection CDs does not violate any laws, and the situation will not change when the EU's Copyright Directive comes into force at the end of this year"

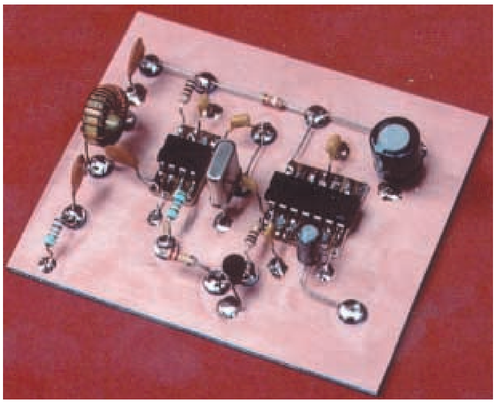
FREE METER!

TO CELEBRATE the launch of its new On-Line store, Lascar Electronics is giving away a free multimeter to anyone who visits their website site and spends over £50 (ex. VAT and carriage) on any of the digital panel meters, data loggers or power supplies listed. The DMM 350 multimeter is equipped with five functions and 19 ranges, with each test position selected by a simple turn of the function/range rotary selector switch. The promotion is available while stocks last.

For more information contact Lascar Electronics Ltd., Module House, Whiteparish, Salisbury, Wilts SP5 2SJ. Tel: 01794 884567. Fax: 01794 884616.

Email: lascar@netcomuk.co.uk. Web: **www.lascarelectronics.com**.

COPPER ISLAND



NO – not a suggestion for where to go on holiday, Copper Island is a printed circuit board manufacturing technique! It is said to make electronic construction faster and easier than ever before, and without chemicals or drilling.

The quick and easy-to-use technique utilises specially shaped "pads" that are made of copper laminate. These are glued to a copper laminate base board to implement your design. The pads are then used as electrically isolated "copper islands". Your components are soldered between the pads, and from the pads to the baseboard wherever ground connections are required, the baseboard acting as the ground plane.

This system seems like it could be a boon to home electronics and radio constructors where prototypes, one-offs, or a small number of boards are required without the need to make p.c.b.s in the normal way.

The Copper Island Construction Outfit is a complete 262-piece self-contained kit. It is housed in a neat compartment box with a hinged lid and contains pads for 8, 14 and 16-pin i.c.s, round pads for leaded components and special pads for miniature screened r.f. coils.

Adhesive, tweezers, pressure rod and an abrasive cleaning block are also included, plus two sheets of copper laminate boards measuring 150mm x 100mm. Full instructions are enclosed and extra pads and "top-up" materials are available.

The kit is priced at £15 plus £2.95 UK P&P (no credit/debit cards please). It is available by mail order from J. D. Walters, 11 King George V Avenue, Mansfield, Notts, NG18 4ER. Tel: 01623 465443. Web: **www.copperisland.biz**.

NATIONAL VINTAGE COMMUNICATIONS FAIR

SUNDAY 5 May 2002, the National Vintage Communications Fair will be held at N.E.C. Birmingham. It is open from 10.30am to 4.00pm at an entry price of £5 (under 14's free).

It will be the Tenth Anniversary Special and there will be masses of vintage wireless sets, crystal sets, valve amplifiers, classic hi-fi, horn loudspeakers, record players, gramophones, early televisions, old telephones, records, valves and spares, plus all sorts of mechanical and electrical antiques and collectables. The fair is scheduled to have 300 stallholders – one of which will be our sister publication *Radio Bygones.*

For more information contact N.V.C.F., 13 Belmont Road, Exeter, Devon EX1 2HF. Tel: 01392 411565.

Email: sun.press@btinternet.com.

Web: **www.anglefire.com/tx/sunpress**.

WYTHALL RALLY

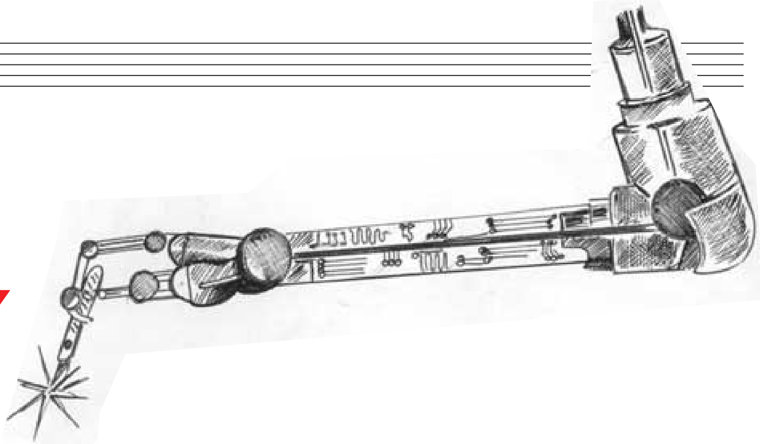
SUNDAY 10 March 2002, the 17th annual Wythall Radio and Computer Rally takes place at Wythall Park, Silver Street, Wythall, near Birmingham, on the A435 just two miles from junction 3 of the M42. Doors open from 10am to 4pm. Admission is £1.50.

There will be plenty of traders in three halls and a large marquee. Bar and refreshment facilities are on site and there is a bring and buy stand. A free park and ride service is provided.

For more information contact Rally organiser Martin G8VXX on 0121 474 2077, evenings. Fax: 0121 742 3471, working hours. Talk in on S22.

Email: enquiries@wrcrally.co.uk. Web: **www.wrcrally.co.uk**.

CIRCUIT SURGERY



ALAN WINSTANLEY and IAN BELL

We offer some advice for selecting the right battery for your project, and describe four-layer semiconductor devices.

The Right Battery

Our thanks to ***John Roberton*** who writes:

I'm having problems with some of my electronics projects. When I build them and switch on to check how well they function, I have notice that when testing it with my multimeter, the voltage across the supply line is much lower than the required voltage which is 9V. I have used several brands of PP3 9V battery but I'm not sure whether I'm using the right type.

It was recommended I use a PP9, which did work but it was too large. I would prefer to use a smaller PP3 battery, but could you please give me any suggestions of what type of battery I could use. Thank you,

John Robertson, by Email.

Choosing the right battery for your projects, John, depends on several factors, the main aim being to match the battery against the supply voltage and current needed by your circuit. Having picked the correct battery voltage (9V), you have to consider the **capacity** of the battery. What is the right capacity depends on how much current you want to draw and for how long.

You'll have to calculate the current or measure it with an ammeter. A battery's capacity is measured in ampere-hours and it indicates how much current the battery can supply over time, before its voltage starts to fall (the battery goes "flat").

The capacity is related to size and the battery's chemical composition, and for electronic projects you will probably use alkaline batteries rather than zinc chloride or carbon zinc types. I couldn't find any data for the PP9 battery you used, these are very old fashioned, relatively rare and becoming increasingly obsolete. However, its large capacity meant that it was well suited to powering the portable transistor radios of its era.

These days a 9V PP3 battery (also known as the LR61 or 1604 type) is adequate for many products, because the current needed by circuits is generally far lower, so a lower capacity (therefore physically smaller) battery can provide a stable 9V rail. In industry, the quest is always to provide ever smaller, faster products using lower voltages and smaller batteries, as evidenced by the mobile phone.

The variation in voltage you noticed is partly caused by the ageing effect of the battery. As it starts to "flatten", its internal resistance increases, which starts to restrict the maximum current that can flow and the voltage across its terminals starts to fall. A battery is generally considered "flat" when its voltage drops to 0·8V per cell (noting that a 9V battery contains six 1·5V cells).

Table 1 Comparison of popular battery capacities (from Eveready data)

Size	*Voltage*	*Capacity mAh* Carbon Zinc	Alkaline
AAA	1·5	540	1250
AA	1·5	950	2850
C	1·5	3000	8350
D	1·5	5900	18000
1604	9·0	400	595
908 Lantern	6·0	12000	26000
915 Lantern	6·0	11000	26000
918 Lantern	6·0	n/a	52000

Dips and Tips

If the load current increases, then the battery voltage will dip as you observed. To help overcome these dips, it is very common to place a large electrolytic capacitor (say 100μF to 470μF) across the supply lines, which acts as a reservoir for the battery, helping to ensure that enough current can be supplied to the circuit at peak times, until the performance becomes so bad that the battery must be changed.

The other likely reason for those voltage dips is that the battery, even a new one, just hasn't sufficient capacity to start with: it's too small. If you "shunt" a battery by drawing a very great current, inevitably the voltage across its terminals will fall. The only answer is to increase the capacity of the supply, and if 9V is required you have no choice but to use separate 1·5V cells in a battery holder instead.

A rare (old) traditional 9V battery compared with a 9V PP3 type battery (centre) and a 9V power pack using six AA (1·5V) cells in a holder.

The web site of Eveready Batteries at **http://data.energizer.com** provides data sheets for most of their products. Their consumer alkaline range includes the 9V 1604 type, which has a stated capacity of 595mAh, which means that it could in theory supply 595mA over the duration of one hour before the voltage tailed off too much.

To give you some idea, Eveready states that capacity figures are based on a 25mA continuous current to 0·8V cut-off per cell. So once you calculate or measure the current drawn by the circuit, you will start to get an idea of battery suitability.

Compare this with an individual 1·5V cell: an Eveready AA alkaline cell has a stated capacity of 2850mAh (2·85Ah). Put six of them in series and you have a 9V 2850mAh battery pack with nearly five times the capacity of a PP3, but

of course it is physically larger. Connect them all in parallel, and you would have a 1·5V battery with a 17·1Ah capacity instead. (Think about how we calculate the value of capacitors in series or parallel.)

By way of comparison, an Eveready 918 6V Lantern Battery has a capacity of 52000mAh (52Ah) which is as much as some 12V car batteries can manage. Table 1 is a summary of battery capacities as published by Eveready. (While on the Eveready site, be sure to read their fascinating *History of the Eveready Flashlight.*) I hope that helps. *ARW.*

Four Layer Devices

Sam Carson asks in the *EPE Chat Zone* (the message board on our web site, **www.epemag.wimborne.co.uk**):

Could anyone tell me what it means if something is a "four layer semiconductor device"? I am unsure of this term.

A thyristor, also known as an SCR (silicon controlled rectifier) is described as a four-layer device because, as can be seen in Fig. 1 it is constructed from four layers of silicon of alternating type (that is, *p-n-p-n* (*p* and *n* type semiconductor). Compare this with a bipolar junction transistor (bjt) which is three-layer – either *p-n-p* or *n-p-n*. The thyristor is constructed like two overlapping transistors – the *np* of a *pnp* transistor which overlaps the *np* of an *npn* type, as indicated by the dotted boxed in Fig.1a. This leads to the transistor equivalent circuit in Fig.1b. The circuit symbol of a thyristor is shown in Fig.1c.

The thyristor is a unidirectional device, meaning that, like a diode, current will only flow one way through it (from anode to cathode). However, if we simply apply an anode-cathode voltage no current will flow until the device is *triggered* by a gate current. This is not like a transistor, however, which turns off again if the base or gate current is removed; the thyristor's anode-cathode current *continues to flow* even if the gate current stops. It will only stop when anode-cathode voltage is removed or if the anode-cathode current drops below a certain minimum level. Thus the trigger current causes the thyristor to *latch* on.

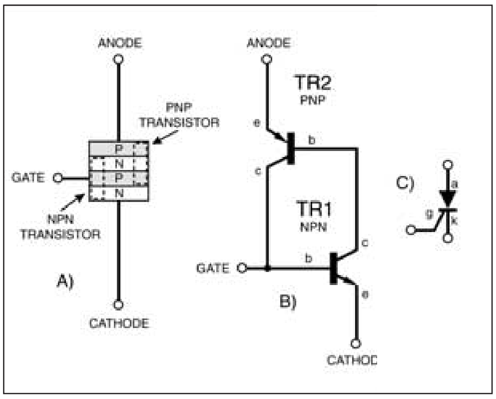


Fig.1. (a) Four layer pnpn *construction of a thyristor (SCR), (b) equivalent circuit, (c) circuit symbol for an SCR.*

We can understand this behaviour by looking at the equivalent circuit of the thyristor in Fig.1b. The "trigger" gate current turns on transistor TR1. The collector current of TR1 provides a base current for TR2, turning that on too. In a similar manner the collector current of TR2 provides more base current for TR1 turning it on even more. This is a positive feedback effect that quickly ensures that both transistors conduct. Once the gate has triggered this condition is self-sustaining, so gate current is no longer needed. The thyristor can only be turned off by reducing its anode-cathode current below some critical point, known as the *holding current.*

The gate current is unfortunately not the only way to turn on a thyristor. A sufficiently fast rising anode-cathode voltage can also trigger the device, due to the capacitances inherent in the thyristor's structure. To prevent this, *RC* snubber circuits can be used to reduce the rise-time of voltages across the thyristor, which has been dealt with in this column in the past.

The voltage across a thyristor when it is ON typically has a minimum value of around 1V, but may be higher (2V to 3V) for high current devices; the ON current can be very high (tens of amps in high power devices). The OFF current is very small – a leakage current. The maximum OFF voltage (supply voltage) can be very high – hundreds of volts in high power devices.

The trigger current must be applied for long enough to allow the device to turn on (typically microseconds, but this varies between devices). Thyristors also take a time to switch off (maybe tens or hundreds of microseconds, again this varies a lot between different types). *IMB.*

Special Feature

PROGRAMMING PIC INTERRUPTS

MALCOLM WILES

Part 1

How to use Interrupts successfully with your PIC programs.

THE Microchip PIC family of microcontrollers supports interrupts. However, relatively few of the projects published in *EPE* to date have used interrupts.

Programming a PIC to use interrupts is not completely straightforward (but then sometimes neither is programming a PIC to do anything!) There are some special considerations that need to be borne in mind.

This article gives a general introduction to the topic of writing PIC software to handle interrupts, with special reference to the PIC16x84 and PIC16F87x families, which are the most popular with hobbyists. This article concentrates on how to write programs to handle interrupts. There are also some timing and related issues that need to be taken into account when designing circuits to use interrupts. For full details, please refer to the relevant PIC data sheet.

The assembler dialect used in the examples is MPASM, but translation to TASM (e.g. by *EPE PIC Toolkit Mk2* or *Mk3/TK3*) should be straightforward. The software discussed is available as stated later and includes the source code **.ASM** (MPASM), plus pre-assembled files **.HEX** (MPASM) and **.OBJ** (TASM).

There are several example programs and experiments, all of which are designed to be run on the circuit shown in Fig.1. This could be set up on a solderless breadboard, or on *PIC Toolkit Mk3*. Access to a PIC programmer (such as one of the *EPE Toolkits*) is assumed.

WHAT ARE INTERRUPTS?

An interrupt is an event which causes the PIC to suspend what it is currently doing and execute a special piece of program designed to process that event. When the event has been processed, the PIC resumes what it was doing at the point it broke off.

Interrupts are useful because they free a program from continually having to check ("poll") whether external events that it needs to process have occurred. Instead it can be arranged that the events themselves cause the necessary processing code to be run automatically.

To a PIC, it's maybe a bit like having the phone ring while you're reading a book. You put a bookmark in the book, put it down, pick up the phone and deal with the phone call. When the phone call ends, you pick up the book again and resume reading where you left off.

INTERRUPT CAUSES

On the PIC16x84 family there are four events that can cause interrupts. These are:

- a rising or falling edge (configurable) on the RB0/INT pin
- the TMR0 counter wrapping from H'FF' to 0
- a change on any of the RB4 to RB7 pins (configured as inputs)
- an EEPROM write complete event

The PIC16F87x family adds a further ten interrupt events to this list. Since the principles of handling all interrupts are similar, we won't discuss the ones that are specific to the '87x family in this article.

There are two bits associated with each individual interrupt in the PIC's special function registers. These are:

- an Interrupt Flag bit, which is set when the corresponding event has occurred
- an Interrupt Enable bit, which is set (by software) if the corresponding event is to cause an interrupt. By default, at power up, all interrupt enable bits are set to zero, so that no interrupts are enabled unless the software specifically turns them on.

Enabling an interrupt means that when the corresponding event occurs, the PIC will transfer control immediately to a special Interrupt Service Routine (ISR) to process that interrupt. It does not affect the setting of the interrupt flag bit. If the interrupt is not enabled when the corresponding event occurs, the flag bit is still set, but the ISR is not called. If a flag bit is set and the corresponding enable bit is then set, the ISR will be called immediately.

There is one further bit, the Global Interrupt Enable bit (GIE). This is like a master override switch: if this is zero then all interrupts are disabled, irrespective of the settings of the individual event interrupt enable bits. If the GIE bit is set to 1, then all interrupt events whose individual interrupt enable bits are set will cause interrupts.

Apart from the flag bit associated with the EEPROM Write Complete event, all these bits are in the INTCON special function register. Table 1 lists the INTCON register interrupt bits for the PIC16x84 and PIC16F87x families.

The flag and enable bits for the additional interrupts on the '87 family are located in the Peripheral Interrupt Registers, PIE1, PIE2, PIR1 and PIR2 (see data sheet).

INTERRUPT VECTOR

When an interrupt occurs, the PIC executes a call to program memory Location 4. It is usual to assemble a **GOTO ISR** instruction in this location (as in these example programs), where ISR is the label of the interrupt service routine, although it is possible for the ISR itself to start at

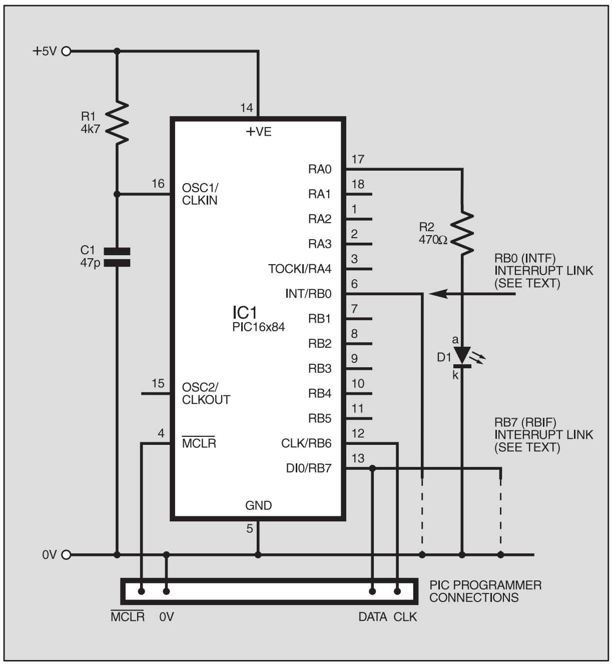


Fig.1. Circuit diagram as used for the Interrupt experiments.

Table 1. PIC16x84 and PIC16F87x INTCON register bits

Bit 7: GIE: Global Interrupt Enable bit
1 = Enables all un-masked interrupts
0 = Disables all interrupts
Bit 6 (x84): EEIE: EE Write Complete Interrupt Enable bit
1 = Enables the EE write complete interrupt
0 = Disables the EE write complete interrupt
Bit 6 (87x): PEIE: Peripheral Interrupt Enable bit
1 = Enables all un-masked peripheral interrupts
0 = Disables all peripheral interrupts
Bit 5: TOIE: TMR0 Overflow Interrupt Enable bit
1 = Enables the TMR0 interrupt
0 = Disables the TMR0 interrupt
Bit 4: INTE: RB0/INT External Interrupt Enable bit
1 = Enables the RB0/INT external interrupt
0 = Disables the RB0/INT external interrupt
Bit 3: RBIE: RB Port Change Interrupt Enable bit
1 = Enables the RB port change interrupt
0 = Disables the RB port change interrupt
Bit 2: TOIF: TMR0 Overflow Interrupt Flag bit
1 = TMR0 register has overflowed (must be cleared in software)
0 = TMR0 register did not overflow
Bit 1: INTF: RB0/INT External Interrupt Flag bit
1 = The RB0/INT external interrupt occurred
0 = The RB0/INT external interrupt did not occur
Bit 0: RBIF: RB Port Change Interrupt Flag bit
1 = When at least one of the RB7:RB4 pins changed state (must be cleared in software)
0 = None of the RB7:RB4 pins have changed state

Additional Peripheral Interrupt Register bits for the PIC16F87x series are located in registers PIE1, PIE2, PIR1 and PIR2 (see data sheet).

Location 4 if preferred. (*EPE programmers prior to TK3 always require a GOTO at Location 4. Ed.*)

Because the **GOTO ISR** instruction is effectively a pointer, it is common to refer to Location 4 as the *Interrupt Vector*.

EXPERIMENTS

Now we have just about enough background to look at an example. First, though, a few practical comments regarding the software and hardware.

The HEX files include Configuration data which is automatically loaded into the PIC when the code is sent to it via *PIC Toolkit TK3* and MPASM-type programmers. The "embedded" code configures the PIC for RC oscillator, power-up timer enabled, watchdog timer disabled, code protection disabled.

However, *EPE* programmers *Toolkit Mk1, Mk2, PIC Tutorial, PICtutor* and the original *EPE Simple PIC16C84 Programmer* cannot handle HEX files or embedded Config data.

In these cases, the Config data must be sent to the PIC in the normal manner required by the programmers before the OBJ program code is sent. The PIC should be configured for RC oscillator, power-up timer enabled, watchdog timer disabled (code protection is automatically disabled with these programmers).

Although RC Oscillator mode is suggested, you may use a crystal oscillator mode instead if you prefer, configuring the PIC accordingly. A suitable crystal would be a 3·2768MHz type (XT mode) although other frequencies could be used instead.

Be aware that if assembling the ASM code yourself, none of the *EPE* PIC programmers can assemble embedded Config instructions or Macro coding structures and that only *Toolkit Mk2 V2.4* and *Toolkit TK3* can handle "Include" files. The exception to this statement is that TK3 can handle embedded Config data in the source code when it is in the form:

```
__CONFIG H'3FF3'
```

The above command (as used in the example source code files) translates for the PIC16F84 as CP off, POR on, WDT off, RC oscillator. The command for CP off, POR on, WDT off, XT crystal is:

```
__CONFIG H'3FF1'
```

Where a programmer/assembler cannot handle such Macro and Include structures, the full equivalent code must be appropriately typed into the ASM file as required, and then assembled. Config values, if your assembler cannot handle them directly, should be sent via the normal Configuration option that you are already accustomed to using.

With the Include file (P16F84.INC), for example, the required Equates defined within it (it is readable as a text file) should be typed into the program in the region where the statement INCLUDE P16F84 is made and this statement should then be deleted (or commented out). You do not need to type in those equates which are not used in the programs. Your Assembler will advise if you miss any.

EXPERIMENT 1

The full source code for the first experiment, INTPROG1, is shown in Listing 1. Load its appropriate INTPROG1.HEX or INTPROG1.OBJ into the PIC (having sent Config data separately if necessary – as discussed above).

This program turns on the l.e.d. connected to PIC port RA0, waits for about a second (with the oscillator rate set as in Fig.1, typically about 2·5MHz for 4k7/47pF), then turns it off again. Connect a wire to RB0 and touch this to a convenient 0V point somewhere. This causes an RB0/INT interrupt (INTF set), and the ISR turns on the l.e.d.

After a variable time up to another second (depending on where it was in the count up to 10 sequence), the main loop turns the l.e.d. back off again. This sequence can now be repeated indefinitely, so touch the wire on 0V a few more times just to see.

CONTEXT

Let's have a close look at the program in Listing 1. Firstly, what's all this **SWAPF** stuff at the beginning and end of the ISR?

Imagine we're just entering the ISR: the main program loop has been interrupted. This can happen between *any* two instructions; exactly where is just a matter of chance depending on exactly when we happen to touch the wire to 0V.

Now suppose the interrupt actually happened between the two instructions:

```
B1:   XORWF COUNT,W
(interrupt occurs here)
B2:   BTFSS STATUS,Z
```

The main program has just done an Exclusive-OR of COUNT with W (which holds a value of 10 from the previous instruction MOVLW 10), and is about to go on and test the Z flag in the STATUS register to see if the result was zero (i.e. COUNT = 10). But in between the ISR will run, and this does an INCF ICOUNT,F instruction. This will overwrite the Z flag. So when the ISR exits, and the main program resumes at the instruction labelled B2, that Z test will be invalid.

Therefore the ISR must save anything before it changes it, and restore it before it exits. The phone analogy used earlier is perhaps not accurate enough; rather than reading a book when the phone rings, imagine you were in the middle of reconciling your bank statement and had lots of sums and calculations part completed on a sheet of paper. It is as if, when you put the phone down, you had obliterated all those calculations with notes of the phone conversation.

The bits and pieces that a program uses as working state are often referred to as its *Context*, and so the preamble and postamble in the ISR is called Saving and Restoring Context.

The most important items of Context on a PIC are the various flags in the STATUS register, and the contents of the accumulator (Working register) W, but there may be others. If the ISR uses indirect addressing, for example, then it will need to preserve FSR. On the '87x family if more than 2K of program memory is used then preservation of PCLATH may become important, as it may on the 16x84 family too if computed GOTO Tables are used other than in Page 0.

The Context preserving instructions in Listing 1 for saving W and STATUS are those recommended by Microchip.

This in itself is an interesting sequence. Why is the rather obscure SWAPF instruction used, and not the more obvious:

```
MOVWF SAVEW
MOVF STATUS,W
MOVWF SAVES
```

Recall that the MOVF instruction affects the Z flag in the STATUS register. Suppose that Z is currently set. If you now do a MOVF STATUS,W instruction, do you expect the Z bit (bit 2) in W to be:

(a) set, because that's how it was in the STATUS register, or
(b) clear, because the MOVF instruction has cleared Z because STATUS was non-zero?

(You might need to wrap a wet towel round your head at this point and think about it!)

The data sheets give no clear answer on this question. The author has tested it on both a 16F84 and a 16F877, and found that it is (a) in both cases. Further, he has found demo code (for a PIC16C745) on the Microchip Website written by Microchip that actually uses the MOVF STATUS, MOVWF SAVES sequence to preserve STATUS in its ISR. So it is probably OK to use this alternative.

The SWAPF instruction does not affect STATUS, so the situation using that instruction is unambiguous. That's maybe why the recommended code is that way. To save our minds boggling too much we will use the Microchip recommended sequence (with SWAPF) throughout this article. Note, however, that STATUS is actually stored in SAVES with its nibbles reversed. On exit, the sequence:

```
POP:    SWAPF SAVES,W
        MOVWF STATUS
```

reverses the nibbles back to the correct order. Now STATUS has been put back it cannot be affected further, so the STATUS non-affecting SWAPF must again be used to restore W:

```
SWAPF SAVEW,F   ; reverse the nibbles
                ; in SAVEW
SWAPF SAVEW,W   ; reverse back to
                ; original order and
                ; load into W
```

Finally, this special instruction is always used to exit from an ISR:

```
RETFIE
```

This resumes the main program at the instruction after it was interrupted. We'll return to this a bit later.

SAVING ADDITIONAL CONTEXT ITEMS

Once W and STATUS have been safely stored, then it's easier to save any other Context items that may need preserving. This is because W and STATUS can now be changed, so there are no constraints on which instructions may be used.

So, for example, to additionally save FSR, the following sequence could be used:

```
ISR: MOVWF SAVEW     ; save W
     SWAPF STATUS,W
     MOVWF SAVES     ; save STATUS
     MOVF FSR,W      ; OK to use
                     ; MOVF and
                     ; change
                     ; STATUS here
     MOVWF SAVEF     ; save FSR
                     ; body of ISR
                     ; goes here
```

LISTING 1

```
; INTPROG1.ASM
; Switch on LED if RB0 interrupt
      LIST P=16F84,R=DEC
      __CONFIG H'3FF3'
; Macros
#DEFINE BANK0 BCF 0x03,5
#DEFINE BANK1 BSF 0x03,5
; Equates for registers
            INCLUDE P16F84.INC ; or type in required Equates here instead
; Data locations
SAVEW:      EQU 0x20            ; preserve W during interrupts
SAVES:      EQU 0x21            ; preserve STATUS during interrupts
COUNT:      EQU 0x22            ; count of timer ticks
ICOUNT:     EQU 0x23            ; number of interrupts
DELAY:      EQU 0x25            ; delay loop counter
; code
            ORG 0
            GOTO INIT           ; Reset vector
            ORG 4
            GOTO ISR            ; Interrupt vector
            ORG 5
; initialise PIC
INIT:       CLRF PORTA          ; initialise all port outputs to zero
            CLRF PORTB
            BANK1
            CLRF TRISA          ; RA0 – RA4 all outputs
            MOVLW B'00000001'   ; RB0 input, rest outputs
            MOVWF TRISB
            MOVLW B'00000111'   ; enable PORTB pullups, falling edge RB0,
                                ; PSA to TMR, prescale /256
            MOVWF OPTION_REG
            BANK0
; interrupt setup
            BSF INTCON,INTE     ; enable INTF (RB0/INT) interrupt
            BSF INTCON,GIE      ; enable global interrupts
; data initialisation
            BSF PORTA,0         ; turn on the LED
; main loop
MAIN:       CLRF COUNT          ; clear ticks count
            CLRF TMR0           ; clear internal clock count-up
A2:         BCF INTCON,T0IF     ; clear the TMR0 wrapped flag
A1:         BTFSS INTCON,T0IF   ; has TMR0 wrapped yet?
            GOTO A3             ; no, go back and wait for it to wrap
            INCF COUNT,F        ; bump count of wraps
            MOVLW 10            ; about 10 bumps/sec at 2MHz clock
B1:         XORWF COUNT,W       ; sets Z if COUNT = W
B2:         BTFSS STATUS,Z      ; test Z
            GOTO A2             ; Z not set so COUNT <> 10
            BCF PORTA,0         ; wraps COUNT = 10 so switch off led
            GOTO MAIN           ; and repeat main loop
A3:         MOVLW 250           ; a short delay loop
            MOVWF DELAY         ; load the delay counter
A4:         INCF DELAY,F        ; bump delay counter
            BTFSS STATUS,Z      ; and test if it's zero
            GOTO A4             ; it's not so spin
            GOTO A1             ; go back and wait for TMR0 to wrap
; Interrupt service routine
ISR:        MOVWF SAVEW         ; save W
            SWAPF STATUS,W
            MOVWF SAVES         ; save STATUS
            BTFSS INTCON,INTF   ; test INTF
            GOTO POP            ; not an INTF interrupt
; there is an INTF interrupt
            INCF ICOUNT,F       ; bump count of interrupts
            BSF PORTA,0         ; turn on the led
            BCF INTCON,INTF     ; clear the interrupt
POP:        SWAPF SAVES,W       ; restore STATUS
            MOVWF STATUS
            SWAPF SAVEW,F       ; restore W
            SWAPF SAVEW,W
            RETFIE              ; exit ISR
            END                 ; of program
```

The POP sequence is straightforward too, noting only that FSR needs to be restored before STATUS is restored:

```
POP: MOVF SAVEF,W   ; restore FSR
     MOVWF FSR
     SWAPF SAVES,W  ; restore
                    ; STATUS
     MOVWF STATUS
     SWAPF SAVEW,F  ; restore W
     SWAPF SAVEW,W
     RETFIE         ; exit ISR
```

The same would apply to saving PCLATH, and to any other register that also needs to be preserved.

EXPERIMENT 2

Suppose that in the main loop of INTPROG1 (Listing 1) there had been an access to data stored in EEPROM. This is illustrated in program INTPROG2 with the addition of the code at A3 and variable EBYTE (equated to 0x24 at the head of the source code); INTPROG1 is otherwise unchanged. The new A3 code is shown in Listing 2.

(The author knows there's no obvious reason for doing an EEPROM access in this simple program, but bear with him because the point illustrated is important.) Load the PIC with INTPROG2. Now repeat Experiment 1.

If you are lucky, you may get the l.e.d. to flash on a few times, but the chances are that the PIC will appear to "die" very quickly, the l.e.d. will stop coming on, and a reset will be necessary to get it going again.

Reset the PIC and repeat the experiment a few times, because as we'll see in a minute there is a large element of chance in how this experiment works.

So what's gone wrong? The EEPROM access code is copied straight out of the PIC's data sheet, so that must surely be OK? See if you can figure it out before reading on.

It's nothing to do with the EEPROM access as such. What has happened is the Context problem in reverse. INTPROG2 works until, by chance, the interrupt occurs between the BANK1 and BANK0 (many readers will be more familiar with the equivalent terms PAGE1 and PAGE0) instructions below A3.

The ISR is entered with the Bank setting bits (RP0 and RP1) set for Bank 1. Thus, when it executes the BSF PORTA,0 instruction, what it actually does is set bit 0 of Location 5 in Bank 1. This is the TRISA register, and so the effect is to make RA0 an input. Hence the l.e.d. on RA0 flashes no more.

Thus after preserving the main program's Context, the ISR has also to establish its own Context. In this case after saving STATUS, the ISR needs to set for Bank 0 as illustrated by the ISR routine section shown in Listing 3. Adding this instruction is the only change from INTPROG2. Load the PIC with INTPROG3, then repeat Experiment 2. This should now work correctly, like INTPROG1.

It is worth noting that the PIC16x84 family only make use of Bank setting bit RP0 and the data sheet states that RP1 should be maintained clear (= 0).

Listing 2. A3 code section for INTPROG2

```
; code to read a byte from EEPROM
A3:  MOVLW 0            ; EEPROM address 0
     MOVWF EEADR        ; into the address reg
     BANK1
     BSF EECON1,RD      ; initiate read
     BANK0
     MOVF EEDATA,W      ; copy EEPROM data to W
     MOVWF EBYTE        ; and store in main memory
     MOVLW 250          ; a short delay loop
     MOVWF DELAY        ; load the delay counter
A4:  INCF DELAY,F       ; bump delay counter
     BTFSS STATUS,Z     ; and test if it's zero
     GOTO A4            ; it's not so spin
     GOTO A1            ; go back and wait for TMR0 to wrap
```

MURPHY'S LAW OF INTERRUPTS

Looking at the A3 section in Listing 2, you might have imagined that the chances of getting an interrupt in the two-instruction interval (BANK1/BSF EECON1,RD) where it would cause trouble were remote. However, Experiment 2 has demonstrated Murphy's Law of Interrupts: if an interrupt *can* occur at the most awkward time, it *will*, and more often than you think.

Code using interrupts needs to be bulletproof against these Context issues, or it will inevitably suffer strange and random failures that are difficult to reproduce and debug.

BANK SWITCHING

The need to be careful is even greater on the '87x family of devices, where there are four Banks and a much greater chance that the Context will not be Bank 0 when the interrupt occurs.

A further issue on the '87x family is that there may be physically separate general purpose memory on up to four Banks (John Becker showed how to access this memory in June 2001 – *PIC16F87x Extended Memory*). This means that, when the ISR is entered, it cannot assume that it has the correct Bank set up to access the save variables and store the main program's Context – and it can't change the Bank setting without corrupting the Context!

Is this an insoluble chicken-and-egg problem? Happily not – on '87x devices there are 16 locations, H'70' to H'7F', which map to the same physical memory independent of the Bank settings.

The simplest solution on the '87x is to locate the ISR's Context saving variables (e.g. SAVES, SAVEW) in this H'70' to H'7F' area, then it doesn't matter which Bank is switched in when the ISR is entered.

On the 'x84 family this problem is masked because there is physically only one Bank of general purpose registers, and accesses to general purpose registers in Bank 1 map automatically to Bank 0.

INTERRUPT SETTING

INTPROG4 is a version of INTPROG3 that uses the PORTB change interrupt (RBIF) to turn on the l.e.d. instead of the RB0/INT interrupt (INTF). A change on any of the pins RB7 through RB4 could be set to cause an RBIF interrupt. Program 4 has been written to switch on the l.e.d. if either of RB7 or RB6 is pulled to 0V, but to ignore changes on RB5 and RB4.

Move the wire from RB0 to either RB6 or RB7. Load INTPROG4 and repeat Experiment 2. The program should work correctly with RB6 and RB7, but not with any other RB pin.

There are several significant differences between INTPROG4 and the previous programs. The source code is shown in Listing 4.

Read through Listing 4 looking particularly at the ISR, and observe that handling the RBIF interrupt is noticeably more complex than handling the INTF interrupt.

Firstly, the PORTB register must be read in order that the changed value is latched by the PIC, otherwise it will not be possible to clear the RBIF interrupt.

Secondly, we don't know which of the RB7 or RB6 pins has changed, and it could be more than one of them, so we have to work that out. A soft copy of the last value read from PORTB is kept to do this.

Thirdly, we only know something has changed, we don't know what (remember that INTF can be configured to interrupt on either a rising or falling edge).

In a more complex program, several interrupt sources might be enabled, i.e. several interrupt enable flags might be set.

LISTING 3. Amended ISR section used in INTPROG3.

```
ISR:  MOVWF SAVEW          ; save W
      SWAPF STATUS,W
      MOVWF SAVES          ; save STATUS
      BANK0                ; ensure bank 0 is set
      BTFSS INTCON,INTF    ; test INTF
      GOTO POP             ; not an INTF interrupt
```

LISTING 4. Main source code listing for INTPROG4.

```
          ORG 0                ; reset vector
          GOTO INIT
          ORG 4
          GOTO ISR             ; Interrupt vector
          ORG 5
; initialise PIC
INIT:     CLRF PORTA           ; initialise all port outputs to
                               ; zero
          CLRF PORTB
          BANK1
          CLRF TRISA           ; RA0-4 all outputs
          MOVLW B'11110001'    ; RB7-4 inputs, RB3-1
                               ; outputs, RB0 input
          MOVWF TRISB
          MOVLW B'00000111'    ; enable PORTB pullups,
                               ; PSA to TMR, prescale /256
          MOVWF OPTION_REG
          BANK0
; interrupt setup
          MOVF PORTB,W         ; clear initial mismatch on
                               ; PORTB
          MOVWF SOFTB          ; and initialise soft copy
          BCF INTCON,RBIF      ; and ensure flag bit is clear
          BSF INTCON,RBIE      ; enable RBIF interrupt
          BSF INTCON,GIE       ; enable global interrupts
; data initialisation
          BSF PORTA,0          ; turn on the l.e.d.
; main loop
MAIN:     CLRF COUNT           ; clear ticks count
          CLRF TMR0            ; clear internal clock
                               ; count-up
A2:       BCF INTCON,T0IF      ; clear the TMR0 wrapped
                               ; flag
A1:       BTFSS INTCON,T0IF    ; has TMR0 wrapped yet?
          GOTO A3              ; no, read the EEPROM
          INCF COUNT,F         ; bump count of wraps
          MOVLW 10             ; about 10 bumps/sec at
                               ; 2MHz clock
B1:       XORWF COUNT,W        ; sets Z if COUNT = W
B2:       BTFSS STATUS,Z       ; test Z
          GOTO A2              ; Z not set so COUNT <> 10
          BCF PORTA,0          ; wraps COUNT = 10 so
                               ; switch off l.e.d.
          GOTO MAIN            ; and repeat main loop
; code to read a byte from EEPROM
A3:       MOVLW 0              ; EEPROM address 0
          MOVWF EEADR          ; into the address reg
          BANK1
          BSF EECON1,RD        ; initiate read
          BANK0
          MOVF EEDATA,W        ; copy EEPROM data to W
          MOVWF EBYTE          ; and store in main memory
          GOTO A1              ; go back and wait for TMR0
                               ; to wrap
; Interrupt service routine
ISR:      MOVWF SAVEW          ; save W
          SWAPF STATUS,W
          MOVWF SAVES          ; save STATUS
          BANK0                ; ensure Bank 0 set for
                               ; PORT access
; first check that it's an RBIF interrupt
          BTFSS INTCON,RBIF    ; test RBIF
          GOTO POP             ; not an RBIF interrupt
; read PORTB and compare with last PORTB value read
; see if either RB7 or RB6 have changed
          MOVF PORTB,W         ; read PORTB – also resets
                               ; the input latches and clears
                               ; mismatch
          MOVWF BPORT          ; and make a working copy
                               ; in BPORT
          XORWF SOFTB,W        ; sets bits in W where
                               ; changes from last value
                               ; read
          ANDLW B'11000000'    ; are there changes in RB7 or
                               ; RB6?
          BTFSC STATUS,Z       ; Z clear if there are changes
          GOTO CLR             ; Z set so no changes – exit
; if RB7 or RB6 now reads 0, switch on the l.e.d.
          BTFSS BPORT,7        ; skip if RB7 reads 1
          BSF PORTA,0          ; if RB7 = 0 switch on the
                               ; l.e.d.
          BTFSS BPORT,6        ; skip if RB6 reads 1
          BSF PORTA,0          ; if RB6 = 0 switch on the
                               ; l.e.d.
; housekeeping
CLR:      BCF INTCON,RBIF      ; clear the interrupt
          INCF ICOUNT,F        ; bump count of interrupts
          MOVF BPORT,W
          MOVWF SOFTB          ; and make an updated soft
                               ; copy of PORTB
; restore Context and exit
POP:      SWAPF SAVES,W        ; restore STATUS
          MOVWF STATUS
          SWAPF SAVEW,F        ; restore W
          SWAPF SAVEW,W
          RETFIE               ; exit ISR
          END                  ; of program
```

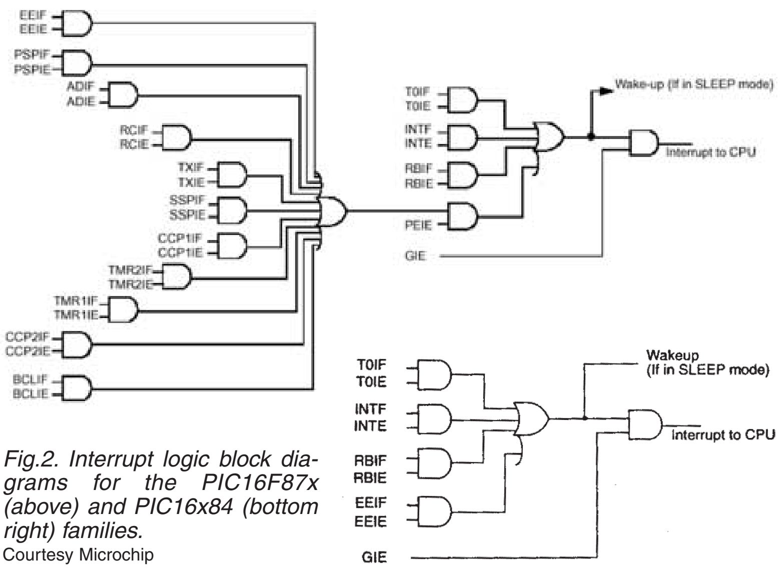


Fig.2. Interrupt logic block diagrams for the PIC16F87x (above) and PIC16x84 (bottom right) families.
Courtesy Microchip

Any one of the corresponding events might have occurred when the ISR is entered. It's also possible that several events might have occurred simultaneously, so that more than one flag bit might be set.

The ISR needs to check for every possibility by reading all the flag bits for which interrupts might be enabled, and to respond appropriately.

Block diagrams of the interrupt logic for the PIC16F87x and PIC16x84 families are shown in Fig.2

OBTAINING SOFTWARE

The demonstration software for this article is available from the *EPE* Editorial office on 3·5-inch (for which a nominal handling charge applies), or *free* from the *EPE* web site. See this month's *Shoptalk* page for more details.

NEXT MONTH

In Part 2, we examine other aspects that need to be considered when using interrupts.

RH METER

BILL MOONEY

Uses a capacitive sensor to measure the Relative Humidity (RH) of air.

ALTHOUGH we consider air to consist of nitrogen, oxygen and a little carbon dioxide, one other component is essential for normal life, namely water. Too much or too little water in our atmosphere soon leads to discomfort and even serious health problems.

Static charge build-up with all its consequences is directly related to low humidity. Air humidity also has large effects on many engineering and building materials in everyday use. Also, without water in the atmosphere we wouldn't have weather, as we know it.

The RH Meter (Hygrometer) described here uses a new capacitive RH (relative humidity) sensing element to give an accurate measure of the relative humidity of air. The sensor contains on-chip integrated signal processing to give a d.c. output proportional to RH. The element is laser trimmed to a preset output span so that a simple but very effective RH meter can be produced without the need for calibration in standard atmospheres.

The traditional analogue meter readout is a visually comfortable way or representing the ambient RH. But a ground referenced analogue output is also provided for PC or PlC recording, processing or data logging.

HUMIDITY

Relative Humidity is a measure of the amount of water in air. The scale covers from 0% which is "bone" dry to 100% when the air is referred to as "saturated''. We are used to living in an atmosphere between about 30%RH and 70%RH.

Above 70% RH things are getting a little humid and over 80% it is downright uncomfortable and rain-forest like. Humid air feels warmer than it really is because of the reduction in evaporative cooling of the skin. In very high humidity conditions, moulds and fungi proliferate but dust mites prefer it slightly less humid at around 60%RH.

There are many other effects of high RH such as breakdown of materials like insulating foams releasing toxic gases and increased warping and break-up of chip board and similar cellulose building composites. At high RH we run the risk of a small drop in temperature suddenly taking the air above saturation. This means condensation or liquid water everywhere. Water in this state is very corrosive, metals rust, paint flakes off, materials which should never get wet irreversibly distort.

LOW LEVEL

Below 30% RH we start to dry out and it feels cooler than it really is because of increased ease of skin evaporation. Humans perceive humidity in part as a temperature effect. Many houses hit 15% RH or lower in late autumn when the central heating comes on. This results in various infections as the protective mucus linings of our mouth and airways dry out.

Apart from low oxygen content a major enemy of Everest climbers and arctic explorers is low RH. The atmosphere is freeze-dried and the human skin becomes dehydrated and brittle and finally cracks.

Similarly, frosty nights can easily result in unhealthy low RH levels. At low RH the electrical resistivity of most materials increases to greater than a million megohms per square ($10^{12}\Omega$). This results in huge static electricity generation and charge build-up. Shocks and discharges from carpets, clothing and cars, become intolerable and, of course, there are increased fire risks.

Atmospheric humidity is particularly important to timber merchants. When we buy wood from the DIY we must select inside or outside conditioned timber. Try using wood which is seasoned and cut outside for your inside shelves and they will warp and crack unacceptably.

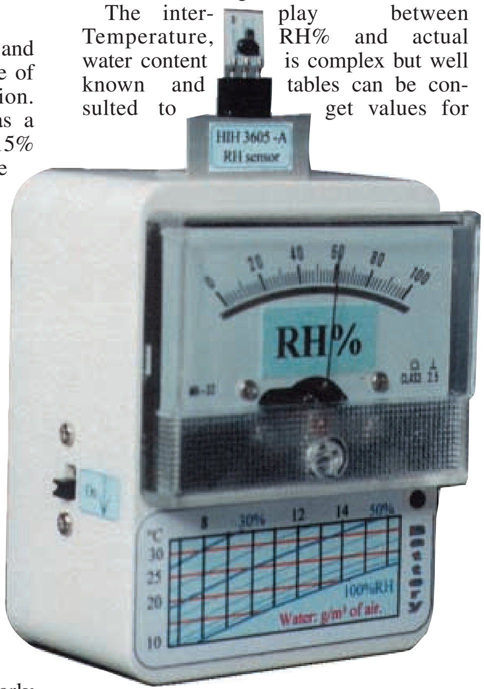
MEASURING RH

There are several ways of measuring and expressing the amount of water in the air, including dewpoint, vapour pressure and wet bulb depression or psychrometery. But Relative Humidity (RH%) is by far the widest used and most familiar descriptor for moisture in air.

The RH scale also corresponds well to our perception of moisture level. RH is defined as the ratio (expressed as percent) of the actual partial vapour pressure to the saturated vapour pressure at the prevailing temperature. Without the temperature RH does not define the actual water content as the water content increases with temperature.

A more intuitive definition of RH is the ratio of the water content of air to its water content at saturation expressed as a percentage. Or simply how close we are to saturation. An example will put some reality into this. One cubic meter of air at 40%RH weighs about 1kg at 10°C and contains about 3 grams of water.

The inter-play between Temperature, RH% and actual water content is complex but well known and tables can be consulted to get values for specific conditions. At some point the amount of water in air reaches a limit which we recognise as saturation or 100% Relative Humidity.



Another example will give a feel for what this means in reality. Taking one cubic meter of air at 50% RH and 20°C, it contains 7g of water. If water is added to this air it will reach saturation or 100%RH at a water content of 14g.

Taking this sample of air at 50% RH/20°C containing 7g of water per cubic meter, if we increase the temperature to 25°C it would need to contain 10g of water to maintain the same 50% RH. This is why many commercial RH meters also contain a thermometer. But even if the temperature is not known the RH figure tells us how

"wet" the air is, which is what we need to know and is therefore a great way of expressing this property.

Finally, and probably to add to the confusion, it must be pointed out that when we refer to the capacity of air to "hold" water and similar phrases we are not strictly correct in physics terms. But it is a useful model. In fact, water vapour behaves quite independently of the other gases so that you could have an RH value for just water vapour in a space. The prevailing pressure of the air/water system is the sum of the partial (independent) pressures of each of the gases.

CAPACITIVE SENSOR

Dew point, Psychrometery, and vapour pressure measurements give accurate direct measures of RH. But these methods require us to take some action such as twirling a wet and dry bulb psychrometer for several minutes just to get a single figure.

Automatic measures which give a varying voltage representing RH are required for control, data logging and automatic PC processing. Such sensors have been around for some time in the form of conductive cells. But the latest capacitive sensors are particularly easy to use, yet give instrument quality accuracy and long term reliability.

The Honeywell HIH3605 device is a good example as it contains on-board interfacing electronics to produce a linear voltage/RH output. The internal elements and the construction of the HIH3605 are shown in Fig.1.

It contains a small planar capacitor made from an absorptive polymer dielectric with porous platinum plates. A top layer of porous polymer on the surface protects the sensor from dust, dirt, and oily contamination. But it should still be treated with care.

When moisture enters the dielectric the capacitance changes in proportion to the mass of water present. The sensing capacitor and the small interfacing circuit are integrated on a ceramic base with just three pins to supply power and for output.

If a stable supply of exactly 5V is used, the output voltage span is from 0·80V to 3·90V for 0%RH to 100%RH at 25°C. The change in this span with temperature is small enough to be ignored for this project, see Fig.2. For example, the 100%RH value drops to 3·50V at 85°C which is a higher temperature than likely to be encountered with this meter. But automatic temperature correction is a simple matter for high temperature applications.

It is usually possible to be confident in the RH readings to within 5%RH, with a little care such as allowing enough settling down time. This is very adequate for our RH Meter and in fact most conditioning systems work to this accuracy. Small fluctuations in RH of 1% or so can still be detected for comparative purposes. Getting very accurate RH measurements is difficult and usually means invoking a complex set of corrections.

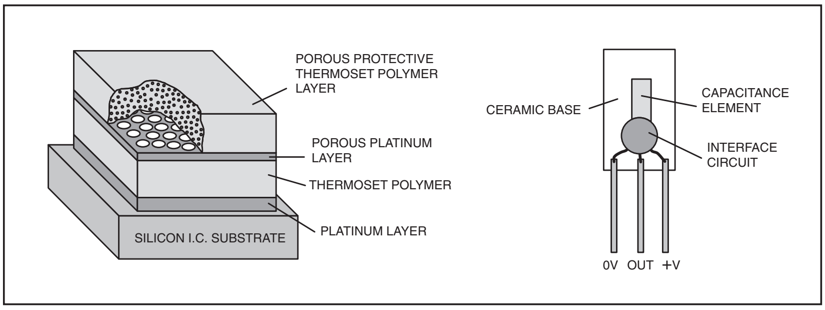
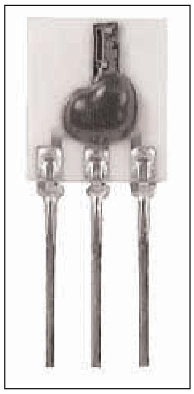


Fig.1 (above). Internal elements and construction of the HIH3605 capacitive RH sensor.



(Right). The Honeywell HIH3605 capacitive RH sensor.

CIRCUIT DESCRIPTION

The full circuit of the RH Meter is shown in Fig.3. After initial setting up, the RH sensor's output (X1) is connected to the non-inverting input at pin 3 of ICla. This is a voltage follower and faithfully delivers the sensor output to the moving coil meter MEl.

The output of IC1a is also the take-off point for output socket SK1 when the signal is required for external processing. A low value resistor R8 protects the i.c. from accidental shorts and has no effect on high impedance loads.

For 0%RH the meter must read 0V but this corresponds to 0·80V output from the sensor X1. A potential divider network consisting of resistors R3, R4 and preset

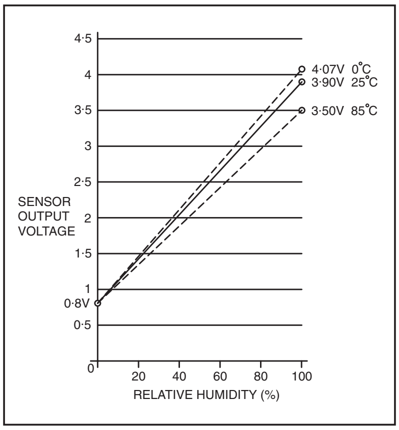


Fig. 2. HIH3605 output voltage for 0% to 100%RH.

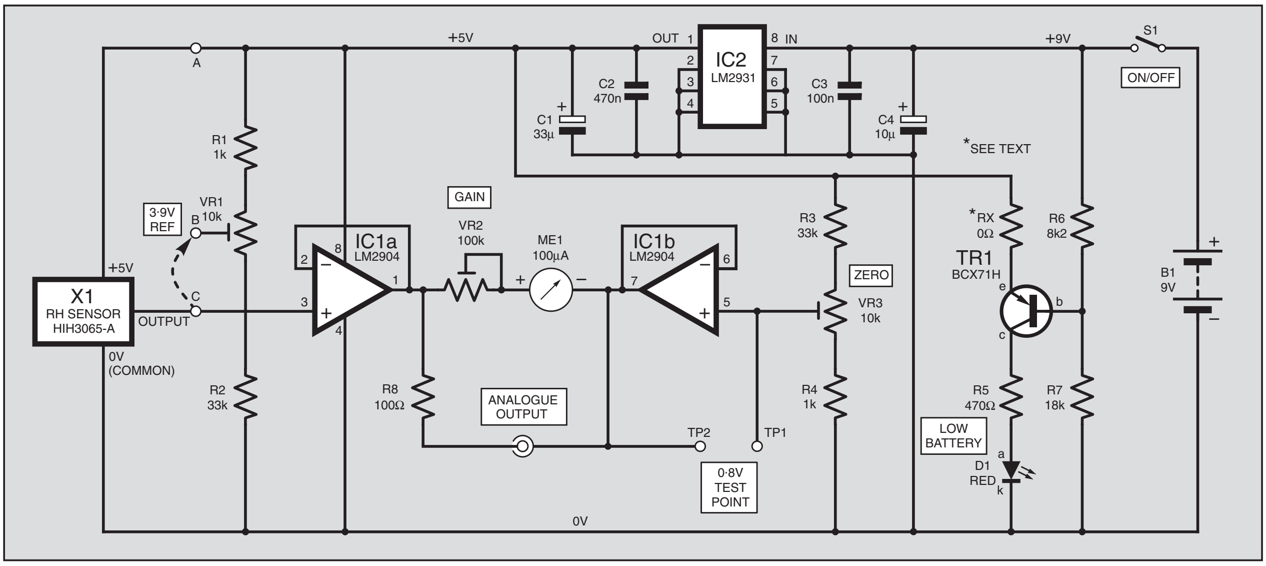


Fig.3. Complete circuit diagram for the RH Meter. Resistor RX is a "zero ohm jumper" but can be an SMD resistor having a value less than 10 ohms or be just a link wire.

VR3 is set to exactly 0·80V and after isolation by IC1b provides a steady 0·80V to meter ME1's negative terminal. When the sensor output is at 0·80V i.e. 0%RH, the meter therefore has 0·80V on *both* terminals and reads 0%RH.

The potential divider made up of R1, VR1, R2 is used as a 3·90V reference for setting up. The output socket, SK1, ground is connected to the output of IClb (at pin 7) and the RH signal is taken from IC1a pin 1 so that a span of 0V to 3·1V represents the full RH scale. Preset VR2 is used for setting the meter ME1 gain to give 100% RH reading at full-scale, see later "Setting Up".

REGULATED SUPPLY

The published calibration for the sensor, which we rely on for this project (it's largely what we pay for) assumes an exact 5V supply. This is provided by IC2 which is a low dropout, low quiescent current, regulator designed for battery equipment. The array of capacitors (C1 to C4) on its input and output pins are essential for its stability.

The LM2931 can operate down to 5·2V thus squeezing the last bit of charge from a PP3 type battery. With a total current drain of just 1·4mA the RH Meter should give up to 400 hours service from an alkaline PP3 battery.

Transistor TR1 drives the low battery indicator l.e.d. D1. Its emitter (e) is connected to the 5V stabilised line. But its base (b) is connected to the unregulated 9V supply through a potential divider made up of resistors R6 and R7. With the values shown, the base reaches 0·6V lower than the emitter at about 5·6V from the battery. At this point TR1 turns on and starts to supply l.e.d. current. The increased internal resistance of the battery and the increased current drain results in a sharp end point.

In the prototype the l.e.d. began to light about 10 hours before a final rapid drop in meter reading and shutdown over a few minutes. This gives sufficient warning that the battery needs changing whilst maintaining an accurate reading.

CONSTRUCTION

The RH Meter is built on a small "surface mount" printed circuit board and the component layout is shown twice-size in Fig.4 for clarity. A full-size (1 to 1) copper foil master pattern is also included in this diagram. Note that the components are mounted directly on the copper pads.

The construction method described here uses surface mount components (SMDs) and some care is needed, particularly with the i.c. leads, when soldering them in place. Although not essential, the application of a non reactive flux pen to the p.c.b. before placement of the SMDs will ensure good solder wetting.

A simple method of placing chip components is to solder one end first. Align the component on the pads and hold it in place by gently pressing it onto the pads. One end can now be soldered to fix it in place. The second end can then be soldered with ease.

Try to use minimal solder and in fact to remove any excess with a solderwick. Minimal solder reduces stress on the chip, which is particularly important for chip capacitors. Particular care should be taken with the high value ceramic capacitors C2 and C3. They can easily crack and the end contacts can detach.

The component marked RX is a zero ohm jumper which is used here for neatness. These devices are used in mass production for minimal inductance which is not important in this application. A low value resistor, less than 10 ohms, could be used or even a wire link for the non-perfectionist.

The two i.c.s can be soldered by fixing pins 1 and 8 first. Pin 1 can be marked on the SO8 i.c. package in several ways,

COMPONENTS

See SHOP TALK page

Resistors

R1, R4	1k (2 off)
R2, R3	33k (2 off)
R5	470Ω
R6	8k2
R7	18k
R8	100Ω
Rx	zero ohm jumper or wire link (see text)

All SM case size 1206

Potentiometers

VR1, VR3	10k (2 off)
VR2	100k

All SM min. preset type 3204 (4mm)

Capacitors

C1	33µ SM tantalum, 16V
C2	470n SM ceramic, case size 1206
C3	100n SM ceramic, case size 1206
C4	10µ SM tantalum, 16V

Semiconductors

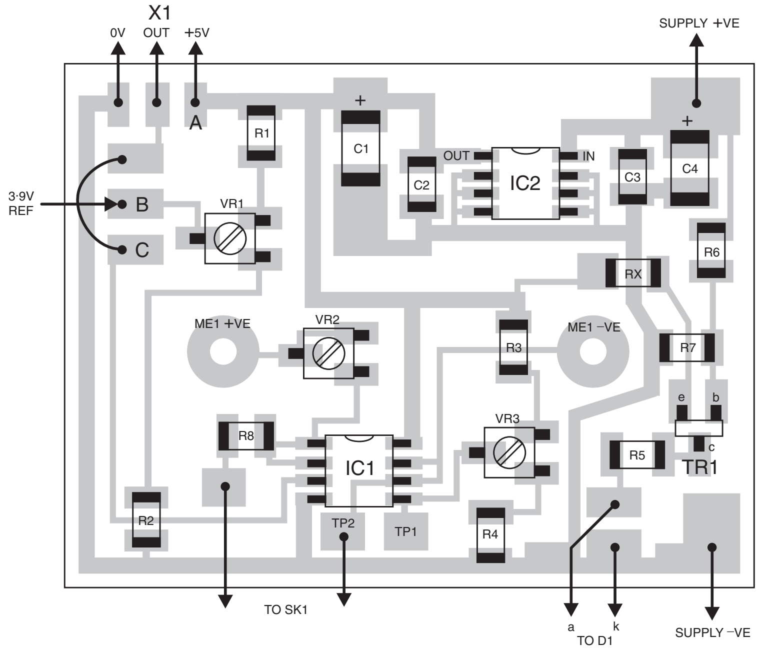
D1	3mm red l.e.d.
TR1	BCX71H *pnp* transistor, SM case SOT23
IC1	LM2904 dual op.amp SM case size SO8
IC2	LM2931 5V regulator SM case size SO8
X1	HIH3605-A capacitive RH sensor

Miscellaneous

S1	s.p.d.t. sub-min. slide switch
SK1	phono socket, chassis mounting
ME1	100µA moving coil panel meter, calibrated 0 to 100, with 60mm x 46mm face
B1	9V battery, with PP3 type connector lead

Printed circuit board available from the *EPE PCB Service*, code 338; plastic case, with brass-threaded inserts for lid, size 79mm x 61mm x 40mm approx.; 3-pin in-line socket for RH sensor; 10mm x 10mm x 1mm thick aluminium angle bracket; multistrand connecting wire; solder etc.

Approx. Cost Guidance Only* £29 *excluding meter & batt.



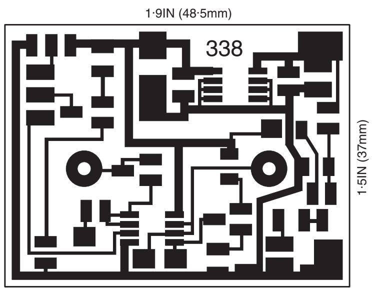


Fig.4. RH Meter surface-mount printed circuit board component layout shown twice full-size for clarity. The full-size master pattern is shown on the right.

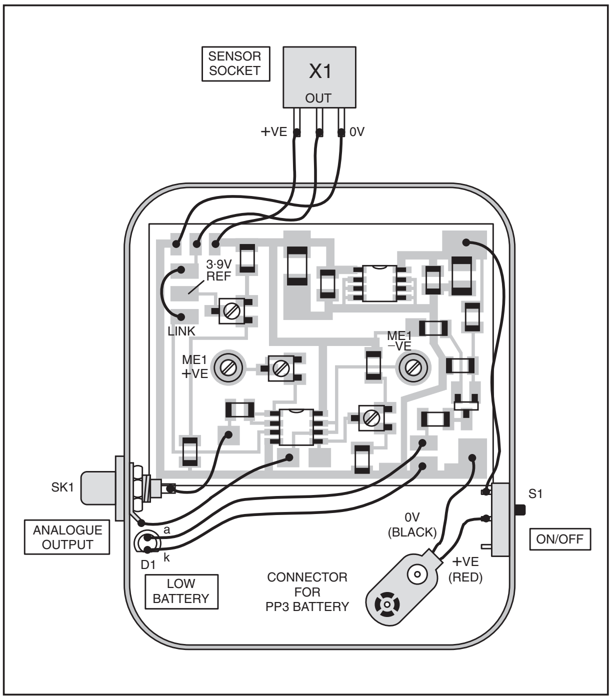
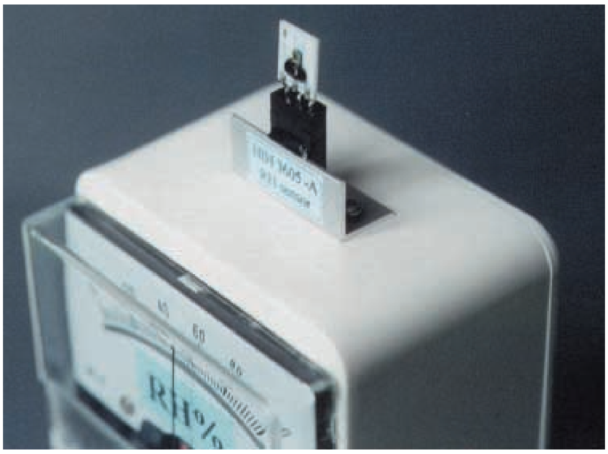


Fig.5. Interwiring from the circuit board to off-board components.



(Above). The sensor plugged into its socket on the top of the meter case.

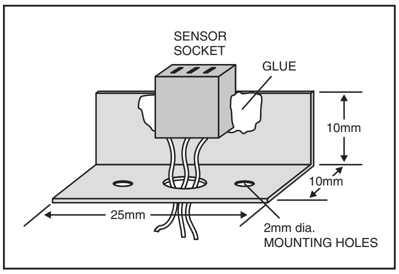


Fig.6 (right). Details of the sensor mounting bracket.

usually by a light band across the pin 1 end. Most SO packages also have a chamfered edge along the pin 1 side. The i.c. pins are very close and a magnifier will be a help to check for any solder bridges.

Transistor TR1 also needs care as the SOT23 case is quite small and any magnetism of the tweezers is quite a nuisance.

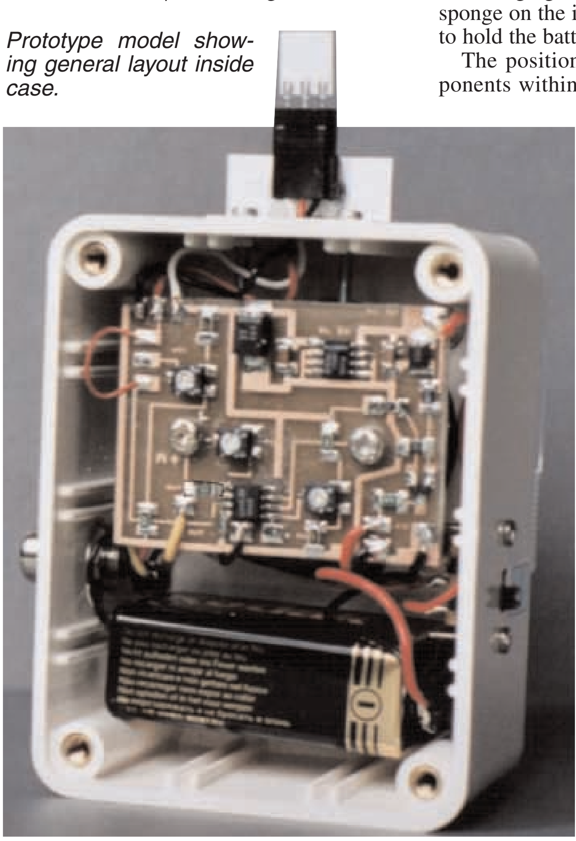
FINAL ASSEMBLY

The p.c.b. conveniently fits onto the back of the 100μA moving coil meter, MEl. The 3mm bolts hold the p.c.b. in place and electrically connect the meter to the circuit. The meter suggested is a very common type with 26mm spacing. If a different meter is preferred, the connection can be made by soldering leads from the meter to the circular p.c.b. pads.

Select a project box (prototype size approx. 79mm × 61mm × 40mm) with metal screw holes for the lid rather than self-tap types as regular access is required for changing the battery. A small piece of sponge on the inside of the lid can be used to hold the battery in place.

The positioning of the off-board components within the plastic case should be finalised and the box drilled out to take these parts. You will need to drill a series of small holes around the required meter cutout and the jagged edges around the resulting larger hole should be smoothed down with a file. The components can now be mounted on the case; the prototype model layout is shown in the photographs.

Prototype model showing general layout inside case.



The interwiring inside the case is shown in Fig.5. The battery condition l.e.d. D1, output socket SK1 and the On-Off switch S1 are all readily accessible and can be wired up after the p.c.b. is fixed in place.

SENSOR

The meter reads up to 100%RH and it is easy to get to this reading in various circumstances. But for extended periods it is probably not so good for the ink-jet decoration on the case, not to mention condensation on the p.c.b.

Monitoring high RH inside test chambers, animal cages and so-on is best done by extending the sensor probe with a 3-way lead. The recommended HIH3605-A sensor comes in a 0·1inch pitch, 3-pin single-in-line (SIL) format. It can be plugged-in or soldered. If a socket is used, it is easy to add a small extension lead when required.

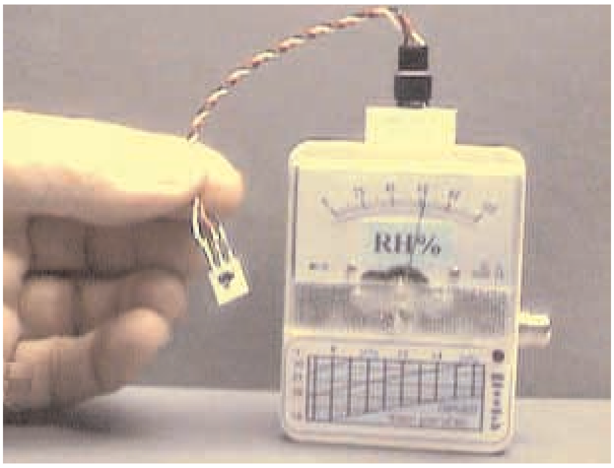
Suitable 0·1in. pitch pre-wired plugs and sockets can be selected from the popular Futaba and other makes used for model radio control work. These are widely available from model shops. It is convenient to cut the socket along with a short length of lead from a ready-made extension. Choose a socket which makes a tight fit.

Run the sensor wires from the circuit board through a small hole in the case "top" to the sensor SIL socket. The socket can be fixed to a short length of 1mm thick, 10mm × 10mm, aluminium angle bracket using rapid setting epoxy, as shown in Fig.6. This bracket can be fixed to the case with two 2mm bolts, see photographs.

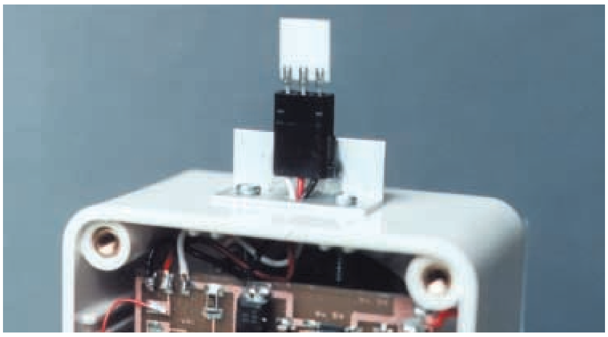
The data sheet suggests that the HIH3605 capacitive humidity sensor is light sensitive. In practice this means direct sunlight. The naked sensor seems insensitive to changes at normal room light levels.

Moving it into weak sunlight from a window causes a small increase in indicated RH%. But bright summer sunlight causes a sudden switch-off. For these conditions therefore, a shield should be made and a black or even translucent 35mm film-tub is ideal. Drill several holes in the cover to ensure good air circulation yet provide shade from direct light.

Finally, the decorative graph, Fig.7, gives useful information on RH, temperature and air moisture content. The RH sensor output pin should not be connected to the p.c.b. meter input, pad C, until the calibration sequence has been completed.



Using an extension lead for non-friendly environments.



Sensor socket glued to the mounting bracket.

SETTING UP

After a really close check on the wiring, the supply current should be checked on first switch-on. There is some spread in the i.c. current drain specifications but the total current should be around 1·4mA.

The first operation is to set the 0·80V reference. Connect a good quality high impedance voltmeter between the test point TP1 on the circuit schematic, which is the VR3 slider, and the 0V (battery –ve) line. Using a small well-fitting screwdriver adjust preset VR3 until the voltmeter reads exactly 0·80V. This should be very simple to achieve if the preset is in good mechanical condition.

Miniature presets like the specified type 3204 have a limited number of reset cycles before the moving contact works loose and the "resistor" value changes a little. Once it is set, VR3 should not need further adjustment. If IC1 operation is correct, this 0·80V reference should appear at IClb output pin 7, which is marked as TP2 on the circuit. This is also a check on the voltmeter and whether it is loading the potential divider chain.

To set meter ME1 to full-scale deflection (f.s.d.) it is necessary to use an accurate 3·9V source. This is provided by the potential divider network around preset VR1 and is available at pad B. Connect the voltmeter between pad B and 0V line and adjust VR1 to give exactly 3·90V, again assuming the test meter does not load the potential source. This should also be stable and need not be set again.

Now solder a temporary link from IC1a input, pad C, to the 3·9V Ref, pad B. This 3·9V signal represents 100% RH and meter ME1 f.s.d. should now be set to 100% using preset VR2.

Moving coil meters require the mechanical zero, on the face of the meter, to be set. Present day meters can be a bit marginal in quality and this adjustment may need to be repeated. This adjustment must be made with the meter held in the vertical position as the makers seem to have lost the art of balancing the meter movement.

Similarly the readings should also be made with the meter vertical. The temporary link from pad C to B can now be removed and the sensor X1 output pin connected to the meter input, pad C. If a meter with a 0 to 100 calibration is used the RH Meter should now be reading the ambient humidity in RH%.

IN USE

Given the many variables, including the analogue output meter mechanics and settling down time, the RH Meter should easily read the actual RH to within a 5 per cent band. The moving coil meter graduations are at 2% intervals so small relative values can be tracked. This is a very small change in RH terms and is more than adequate for most purposes.

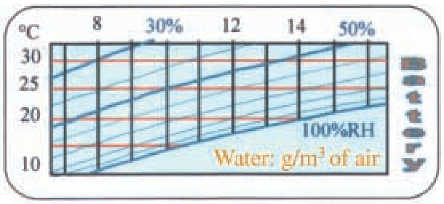


Fig.7. Room temperature RH graph for mounting on the meter case.

Determining absolute RH more accurately than this gets difficult. Individually certified versions of the sensor can be obtained for scientific and close-in control purposes. The fact that the manufacturers can do this is a good indication of the excellent quality and reliability of HIH series technology. Taking the output to a PC using a DAC will allow much smaller changes, from around 1%RH up to the full 100% RH range to be investigated with almost perfect linearity.

To check the operation of the RH Meter and underline our confidence in the calibration it is useful to check the operation. A few simple experiments will get you started in the world of RH.

The sensor is described as chemically resistant and durable in harsh environments. However, it is suggested that the sensing area is treated with care and not handled directly.

The first test is to put a finger tip up close to the sensor, not actually touching it. After a second or so the reading usually rises by about 10% from the body's near-skin humidity. Breathing on the sensor will drive it to about 80%RH, the normal RH of the breath. However, getting in close will drive the reading up to 100% due to condensation as when breathing on a mirror. The meter will stay at 100% for several seconds and will then drop back to the original reading.

Prolonged exposure to such high humidity or contact of the sensor with liquid water for any length of time, results in a temporary 3% shift in the RH reading. In this case the sensor will need to recondition over 30 minutes or more.

The RH of air reduces if the temperature is increased. An example of this is the air flowing through a computer monitor or TV. On a humid day when the ambient humidity was 70% the warm air from the monitor was reading 40%RH. Another example of reducing RH consisted of blowing air from a hair dryer in a room where the ambient RH was 65%. In this case the warmed air passing through the dryer dropped to about 25%RH.

Again a few minutes is needed for the reading to get back to the ambient value. If the sensor itself is warmed it will momentarily loose heat to the air within a couple of millimetres of the sensor reducing its RH.

This kind of experiment soon gives the user a feel for response times, re-settling times and other sources of error. There are many charts available linking RH, moisture content and temperature depending on the particular end use. The small chart shown in Fig.7, and suggested as a decoration for the meter front panel, is useful for getting a general view of the relationship between RH and moisture over typical room temperatures. □

VIDEOS ON ELECTRONICS

A range of videos selected by *EPE* and designed to provide instruction on electronics theory. Each video gives a sound introduction and grounding in a specialised area of the subject. The tapes make learning both easier and more enjoyable than pure textbook or magazine study. They have proved particularly useful in schools, colleges, training departments and electronics clubs as well as to general hobbyists and those following distance learning courses etc

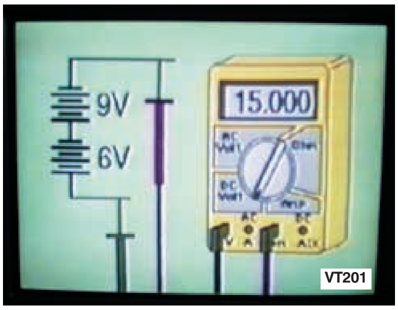
BASICS

VT201 to VT206 is a basic electronics course and is designed to be used as a complete series, if required.

VT201 54 minutes. Part One; **D.C. Circuits.** This video is an absolute must for the beginner. Series circuits, parallel circuits, Ohms law, how to use the digital multimeter and much more. **Order Code VT201**

VT202 62 minutes. Part Two; **A.C. Circuits.** This is your next step in understanding the basics of electronics. You will learn about how coils, transformers, capacitors, etc are used in common circuits. **Order Code VT202**

VT203 57 minutes. Part Three; **Semiconductors.** Gives you an exciting look into the world of semiconductors. With basic semiconductor theory. Plus 15 different semiconductor devices explained. **Order Code VT203**



VT204 56 minutes. Part Four; **Power Supplies.** Guides you step-by-step through different sections of a power supply. **Order Code VT204**

VT205 57 minutes. Part Five; **Amplifiers.** Shows you how amplifiers work as you have never seen them before. Class A, class B, class C, op.amps. etc. **Order Code VT205**

VT206 54 minutes. Part Six; **Oscillators.** Oscillators are found in both linear and digital circuits. Gives a good basic background in oscillator circuits. **Order Code VT206**

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VCR MAINTENANCE

VT102 84 minutes: Introduction to VCR Repair. Warning, not for the beginner. Through the use of block diagrams this video will take you through the various circuits found in the NTSC VHS system. You will follow the signal from the input to the audio/video heads then from the heads back to the output. **Order Code VT102**

VT103 35 minutes: A step-by-step easy to follow procedure for professionally cleaning the tape path and replacing many of the belts in most VHS VCR's. The viewer will also become familiar with the various parts found in the tape path. **Order Code VT103**

DIGITAL

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VT301 54 minutes. Digital One; **Gates** begins with the basics as you learn about seven of the most common gates which are used in almost every digital circuit, plus Binary notation. **Order Code VT301**

VT302 55 minutes. Digital Two; **Flip Flops** will further enhance your knowledge of digital basics. You will learn about Octal and Hexadecimal notation groups, flip-flops, counters, etc. **Order Code VT302**

VT303 54 minutes. Digital Three; **Registers and Displays** is your next step in obtaining a solid understanding of the basic circuits found in today's digital designs. Gets into multiplexers, registers, display devices, etc. **Order Code VT303**

VT304 59 minutes. Digital Four; **DAC and ADC** shows you how the computer is able to communicate with the real world. You will learn about digital-to-analogue and analogue-to-digital converter circuits. **Order Code VT304**

VT305 56 minutes. Digital Five; **Memory Devices** introduces you to the technology used in many of today's memory devices. You will learn all about ROM devices and then proceed into PROM, EPROM, EEPROM, SRAM, DRAM, and MBM devices. **Order Code VT305**

VT306 56 minutes. Digital Six; **The CPU** gives you a thorough understanding in the basics of the central processing unit and the input/output circuits used to make the system work. **Order Code VT306**

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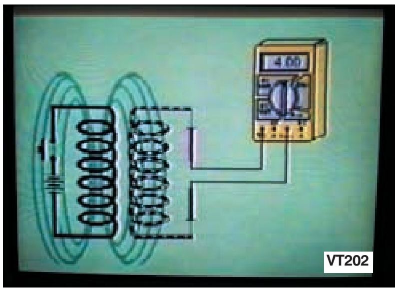
VT401 61 minutes. **A.M. Radio Theory.** The most complete video ever produced on a.m. radio. Begins with the basics of a.m. transmission and proceeds to the five major stages of a.m. reception. Learn how the signal is detected, converted and reproduced. Also covers the Motorola C-QUAM a.m. stereo system. **Order Code VT401**

VT402 58 minutes. **F.M. Radio Part 1.** F.M. basics including the functional blocks of a receiver. Plus r.f. amplifier, mixer oscillator, i.f. amplifier, limiter and f.m. decoder stages of a typical f.m. receiver. **Order Code VT402**



VT403 58 minutes. **F.M. Radio Part 2.** A continuation of f.m. technology from Part 1. Begins with the detector stage output, proceeds to the 19kHz amplifier, frequency doubler, stereo demultiplexer and audio amplifier stages. Also covers RDS digital data encoding and decoding. **Order Code VT403**

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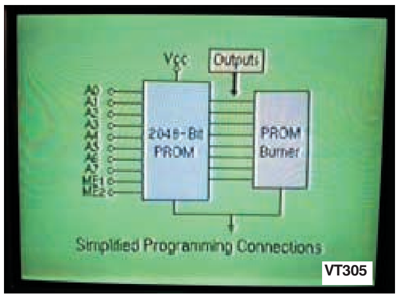
VT501 58 minutes. **Fibre Optics.** From the fundamentals of fibre optic technology through cable manufacture to connectors, transmitters and receivers. **Order Code VT501**

VT502 57 minutes. **Laser Technology** A basic introduction covering some of the common uses of laser devices, plus the operation of the Ruby Rod laser, HeNe laser, CO_2 gas laser and semiconductor laser devices. Also covers the basics of CD and bar code scanning. **Order Code VT502**



Each video uses a mixture of animated current flow in circuits plus text, plus cartoon instruction etc., and a very full commentary to get the points across. The tapes are imported by us and originate from VCR Educational Products Co, an American supplier. We are the worldwide distributors of the PAL and SECAM versions of these tapes. (All videos are to the UK PAL standard on VHS tapes unless you specifically request SECAM versions.)

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READOUT

E-mail: editorial@epemag.wimborne.co.uk

John Becker addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!

WIN A DIGITAL MULTIMETER

A $3\frac{1}{2}$ digit pocket-sized l.c.d. multimeter which measures a.c. and d.c. voltage, d.c. current and resistance. It can also test diodes and bipolar transistors.

Every month we will give a Digital Multimeter to the author of the best *Readout* letter.

★ LETTER OF THE MONTH ★

ELECTRONIC COURSES

Dear EPE,

I am a teacher of Design Technology currently specialising in teaching electronics in a secondary school in Lancashire. This is a new subject for us at GCSE and I have been encouraged in my teaching through a scheme supported by Marconi, amongst others. The most general aim of the scheme is initially to encourage all schools in the country to offer an electronics based course at GCSE.

Recently I have been selected to train as a trainer for other teachers and am currently undergoing accreditation to do this. Part of this accreditation involves a research project. I have decided to look at the relevance of the current approach to GCSE examinations with regard to electronics education in the widest sense, so I was interested to read your *Editorial* in Jan '02.

Although members of the Marconi scheme possess a variety of approaches, I think we all agree that our target is to produce students who are capable of studying for higher electronics qualifications and then move into industry as innovators, technicians and professionals.

As part of the scheme members are currently working on a new ECT (Electronic and Communications Technology) syllabus which we hope to offer as an examination in the next few years. We are just as concerned as you at the way some examination boards are effectively discouraging schools and students from being creative with electronics.

I personally am trying very hard to move away from component based teaching to a mainly systems approach, but I feel that this conflicts with the Board's expectations of students. We are being asked to equip students with such specific knowledge that the subject becomes difficult to teach in the two years of Key Stage 4 and, therefore, many schools are having to target students with this knowledge in the three years before that. This I am sure discourages students who do not get more of an overview of the hi-tech work, which they are actually capable of producing, using modern software and chips. They could be put off the subject before they even attempt GCSE.

I would be really interested to take this discussion further and would be grateful if any readers who have any contacts in industry or further education who would be willing to speak to me about what they expect from GCSE students. I am happy for you to quote my email address.

Simon Wolf, via email,
wolf@horwich14.freeserve.co.uk

Thank you Simon, it is good to have a positive approach to electronics education being expressed through these pages. We hope you receive a wealth of feedback through your email address.

PIC LEARNING

Dear EPE,

I am relatively new to electronics and have worked my way through your excellent *Teach-In 2000* course. I'm a partner in a market-gardening business and have used some of the ideas from the course to design (I use the term loosely!) a fairly simple irrigation controller for our polythene tunnels. We're organic growers and rather low-tech so some of the more sophisticated and expensive proprietary controllers on the market wouldn't suit.

Building this one successful design has whetted my appetite and having been aware of the great use of PIC microcontrollers through the pages of your magazine, feel I'd like to learn about them. Although there's obviously a great deal of information around both in *EPE* and from other sources, being a novice in electronics in general and programming in particular and not having a huge amount of time or indeed cash, can you please point me in the right direction to get me started on the PIC learning-curve? What are the basic essentials? For instance, would I be able to both program and teach myself about PICs from scratch using your *Toolkit TK3* and the software or would I need more basic information?

Barry Ward, via email

Hi Barry, it's always good to know when people have been inspired by something I've designed or written! PICs are certainly capable of controlling irrigation, as my PIC Water Monitor *of Sep '01 might suggest.*

To learn about PICs I still maintain that my 3-part PIC Tutorial *of March to May '98 is the best inexpensive way. Copies of the texts are available at the usual Back Issue prices. The CD-ROM version* (PICtutor) *is also recommended as it provides a simulation interface which allows you to experiment with writing simple PIC codes and observe them being processed on-screen. Both routes have their own development p.c.b.s, that for PICtutor is professionally manufactured, whereas that for the '98 version is for self-construction.*

TK3 is not suitable as a learning guide – it is a programming system for more experienced programmers.

MSF SIGNAL REPEATER

Dear EPE,

Would it be possible that Andy Flind's *MSF Signal Repeater* design of July '98 would work in a similar application with the WWVB signal here in the USA? I have an application where we are trying to use several of the new low cost auto-set clocks in a factory.

Steve Davenport,
Laurinburg, NC, USA,
via email

Andy says he does not know but thinks that it probably only requires the frequency to be retuned from 50Hz to 60Hz.

MEMORY AIDS PLUS LINUX

Dear EPE,

Thanks for the explanation in *Circuit Surgery* (Jan '02) concerning the equation $f = 1/2\pi RC$. I too have always struggled with dozens of zeroes in my calculations and often got results which seemed to be wrong by a factor of a million or so, give or take a couple of billion. Here are a couple of memory aids which I find useful:

NPN and *PNP* transistor symbols: *NPN* – Not Pointing iN, *PNP* – PoiNting at Plate (referring to the arrowhead on the emitter). I'm not proud of it, maybe readers can think of something better, but it works for me.

I was pleased to see Craig Shelly's letter (Jan '02), particularly the paragraph about Linux. I built an intranet server, using *Red Hat* Linux and *Apache*. It ran "24/7" for months without a single hiccup and only stopped when a Microsoft devotee switched the machine off. Linux appears to be very stable indeed, though I have to admit that I keep it on a separate hard disk on my home PC, in an inexpensive drive caddy. That way I can be sure that my Win 98 disk won't get overwritten, or vice versa.

I think that Linux would be a good platform for any electronics projects which involve connection to a PC. The latest versions of Windows make it very difficult to talk directly to the hardware ports. This is a problem with Win 2000, XP and NT. The huge size of these operating systems also means that it is virtually impossible to re-use obsolescent PCs for hobby purposes. The required disk space and RAM upgrades would cost too much, and an "old" Pentium 100 would practically die under the burden. Have you looked at the implications of talking to the hardware directly under Linux? I suspect it will work but I need to be sure.

Jon Lester, via email

Thanks for your comments Jon. No, I have not investigated Linux. To be intentionally provocative, we've had a fair bit correspondence in Readout *on Linux, but no-one has ever offered us a project that was based on it. What are you all doing with Linux apart from telling us how good it is?!*

Incidentally, talking about re-using old PCs, a BBC Radio 4 program recently suggested that anyone with a working but unwanted PC should offer it to a charity organisation for their own use – apparently there are many without computer facilities and who could benefit from the simple facilities of an older machine.

TK3 AND LAPTOPS

Dear EPE,

In the article on *Toolkit TK3* you ask for feedback about using it with laptops. I have been using it on a Compaq Armada 1592 laptop (P233 64MB and Win 95 osr2) – originally on the old hardware. I recently received the new hardware as a kit from Magenta and have now used this as well without any problems! I also added my text editor of choice, EDITPAD – free for private use, download from **www.editpadlite.com**.

I Like the new software and hardware and found them both easy to use.

Bob Allan, via email

Thanks Bob, that's useful info which I am pleased to share with readers.

EDUCATIONAL FAILINGS

Dear EPE,

I recently retired as an electrical technician owing to ill health and decided to enter the teaching profession. Technically I thought that my skills were reasonable (I have an HND and a Post Advanced Diploma in Power Engineering).

I took up a course to gain a teaching certificate and whilst doing so I was approached by a chap who was about to set himself up as a Private Training Provider operating within a local college. Unfortunately the entrants were of such low quality he could not offer any electrical subjects, the learners' knowledge of mathematics was abysmal and so I was asked to teach mechanical engineering subjects. Recall that we in the electrical industry had made the change to metric many years ago .

But worse was to come, most of the drawings were in Imperial units. I saw at first hand how much difficulty learners had using Imperial measurements when they had only been taught in metric. I thought it immoral to use Imperial units when colleges and schools were forbidden to do so, but under the Blair Public/Private initiative Private Training Providers seemed exempt from this ruling. And according to our national body EMTA, the Engineering and Manufacturing (used to be called Marine) Training Authority, we had to teach what employers wanted and the claim was made that Employers did want Imperial!

I felt that we as a country would never make the progression to be European unless we did what the Government dictated in the sixties: become a metric nation. Before I resigned through frustration I made representations to the Training Body and the departments of trade and industry and the department of Education and found that no one wanted to rock the boat, all claimed that we have to use Imperial because we deal with North America.

I did eventually get a concession from EMTA in that they then claimed that we only needed to "teach a knowledge of Imperial units". Which is a million kilometres away from "Competence in" which an NVQ is supposed to be about.

My arguments that the rest of Europe also have dealings with the USA and that they did not use metric was to no avail. I argued that we have a factor by which every Imperial dimension could be converted to metric and visa versa (i.e. 25·4mm = 1 inch) and hence there was no problem.

Now do not get me wrong I have no problems with the use of Imperial if Employers actually want that. But remember my employer only got the poorer quality learners, usually those without any worthwhile GCSEs, i.e. Ds, Es and ungraded. They had beautiful gold embossed school leavers' portfolios full of awards for good attendance etc.

It was whilst working at the college I saw that every time the college tried to offer more worthwhile subjects, such as Programmable Logic Controllers (another of my interests), there was virtually no interest and the planned courses had to be cancelled. The same has happened at another local college that franchised out the teaching of City and Guilds courses in electronics to a private training provider who has since virtually ceased offering the electronics (it is still advertised but not actually offered.) He now concentrates on offering The European Computer Driving License and a C&G networking course. Both colleges spent thousands of pounds on buying PLC equipment which is now lying dormant and which incidentally would not have been purchased by the private sector because they need to show a profit.

I believe that eventually I saw what was happening. It would appear that we should really raise our school leaving age to 18 or 19, because the old technical colleges have had to lower their standards to accommodate the poorer quality intake and the universities have done likewise so that only by attending University can one reach the level of qualifications, which I gained by college.

The general school leaving standard is now so very low. Going to college should now be regarded as simply continuing school education. Perhaps this is why 16-year-olds can no longer claim unemployment benefit? Our only saving grace is that the better students do go to university, but this means that employers can only get suitably educated staff by recruiting university graduates.

Herein lies the problem for the older generation, modern employers do not realise how much experience and knowledge older technicians have, who get discriminated against. My last employer asked all his electricians and mechanics to become NVQ qualified and to a man they resisted because they quite rightly said that they had been there for up to 20 years and if the employer did not think they were competent then fire them. The employer said that they had to prove to the operator that they only employed competent technicians. Most of us had ONCs and some like me had HNDs/HNCs and even one had a degree but the employer stated that we all had to become NVQ qualified.

When I studied for a teaching certificate it included an NVQ assessor's award, what is called a D32/D33, and we were taught that medical doctors, for example, would be regarded as having been qualified to NVQ level 4 or 5. I suggested that if I am insulted by being regarded as having an NVQ how much so would a university graduate be.

The NVQ in fact only proves that one is capable of doing what the employer requires him to do in his normal work. But a great industry has been created and one has to put in many hours of work to present a suitable and assessed portfolio in order to gain the NVQ, a qualification which incidentally was created by the government to reduce paper qualifications but which, in fact, has created a mountain of paperwork both for the candidate and the assessor.

I have also concluded that perhaps the population is such that we will never be able to educate sufficient people to the level that industry require. Perhaps more people of my generation were the lucky ones. I never had a day's unemployment and was sufficiently able not to get myself too specialised.

One final point about the level of our universities. My son gained a first class honours, and his employer in Europe issued instructions that the only university graduates which they will offer employment to will be a very small select group from specific UK Universities because they have found the general output to be below what they require.

Name withheld by request

It is extremely disturbing that we still do not seem to have an education system that satisfies industry's requirements, despite successive changes made by governments of all flavours. The Letter of the Month, from Simon Wolf, does, however, offer hope.

SPELL-BINDING

Dear EPE,

Yet another *magickal* issue of *EPE* – Jan '02! I usually dive straight into *Readout* but I could not resist starting at the proper place (page 1). The ingenuity of Thomas Scarborough never ceases to amaze me. At last I am reading *Teach-In 2002*, it's a little more advanced than previous ones.

Andy Flind's power supply looks a good one, it appears to be based on the traditional design for lab supplies. At first I was concerned about Bart Trepak's *Touch Switch* circuit being live, then I realised that the sensor plate is behind 2-3mm thickness of plastic.

After thinking about the requirements of *PIC Magick Musick* I believe I could do it with only one PIC, but it would need an 8MHz crystal. By the way, I have never encountered a 4MHz PIC that would not run reliably at 8MHz even with XT osc.

Peter Hemsley, via email

Thanks Peter for your kind comments, all author's like praise!

Yes, in principle, it does seem that one PIC could cope with Magick Musick, *but the difficulties of ensuring tonal consistency at all stages of note generation, ultrasonic transmission and reception are extensive. Rather than spend that amount of time, which would not change the ultimate usefulness of the design, I preferred to take the easy route and use two PICs – they are not expensive.*

I too have frequently "over-run" a PIC using a higher oscillator rate than its data sheet specs suggest (only recently I was successfully running an '877 at 10MHz, and then realised it was only the 4MHz version in the socket!). I would not wish to use such techniques, though, in a published article since correct operation could not be guaranteed in all cases.

MAGICKAL SERMONS

Dear EPE,

Regarding the January edition of *EPE* and *Magick Musick*, my father was president of the London Magic Circle many years ago, and won the International Award for Magic three times (magic design). I should use your *Magick Musick* to punctuate my sermons!

Rev. Thomas Scarborough, via email

That's fascinating about your Dad, Thomas. I should have persisted with my original intent for Magick Musick *to generate harp sounds – they really would have been even more appropriate to your preaching!*

BIT MAPS RE-SURFACE!

In Readout *of Nov '01 Javier Fernadez raised the subject of converting bitmaps for use with graphics l.c.d.s and PICs. Ultimately several readers reported that they could not access the web addresses quoted. Querying this with Javier, he responded:*

Yes, indeed, the quoted pdf path does not seem to work any longer. However, it should still be possible to have access to that app-note, by navigating web-page **www.hantronix.com**.

Javier Fernadez, via email

MICROCHIP CD-ROMS

Dear EPE,

I'm looking for somewhere that I can get the "full Microchip 2001 technical library" CD-ROMs that where included with the Oct '01 magazine, or failing that, where can I get the info from the web?

Michael Edwards, Cape Town, via email

Back issues of Oct '01 are still available and if you purchase one you will automatically receive the free CD-ROM. Alternatively, all the info on the CD-ROM is available separately via Microchip's site at **www.microchip.com***. You can also order the CD-ROM from Microchip via that address.*

EGG TIMERS

Dear EPE,

I read the letter from Anonymous Pupil about an egg timer in your Dec '01 issue. You say that since 1990 you have not published such a project. But if you look in Oct '93 you will find a constructional project for an *L.E.D. Sandglass*, by Mark Daniels. I think this was a nice and neat project and I still have this article.

Harry de Groot,
Cape Town, South Africa,
via email

Thanks Harry – when looking at my master list of projects since 1990 it did not occur to me to look under Sandglass (and '93 was "before my time")!

BBC BASIC

Dear EPE,

Please note the popularity of BASIC_on_chip PIC systems! I've worked with many BASIC dialects, from "Integer" and Applesoft through various proprietary "enhanced" TinyBASICs, Microsoft's Q/Quick series, even HP_Technical running on a luggable Unix_in_ROM system (!).

Only the BBC versions had the knack of being intuitive, orthogonal, friendly and fast. So traditional Beeb BASIC lacks the edge of C++, the panache of Java, the rigour of Pascal and ADA, the elegant power of an Archimedes, or the bloated over-kill of VBA . . . who cares?

Beeb BASIC was robust, compact, economical, quick, easy to use, painless to edit, did much remarkably well, and had an integrated, multi-pass, symbolic assembler "up its sleeve" for emergencies. What more can you ask of a utility language ?

Nik, Lifetime secretary of MBUG,
Mersey BBC User Group, via email

You are not alone in such feelings Nik, see Richard Russell's letter that follows!

BBC BASIC AGAIN

Dear EPE,

OK, you dangled the bait so I'll take it! In your reply to Trevor Cattermole's letter (Jan '02) about BBC BASIC you say "In fact most readers have moved on now, and it seems best that they do". Why? What have you got against BBC BASIC (or is it BASIC in general)?

I use BBC BASIC on an almost daily basis in my professional activities for a very well known broadcasting organisation. I know for a fact that it is also used by other professional engineers in the course of their work. It might not be in the same league as Visual BASIC (let alone Visual C++) but nonetheless it is a very useful tool which can often give quick results.

I am not a regular reader of your magazine, but it was drawn to my attention by a reader who has subsequently bought BBC BASIC for Windows.

Richard Russell (G4BAU),
M.A. C.Eng. M.I.E.E., via email.

To which I replied:

Fishing's not really my scene, but Basic certainly is. I learned programming using Commodore PET Basic, found BBC to be just a variant but better in several respects, got into Amstrad's PCs and used GW, followed by the superior QuickBASIC and sidetracked into QBasic (which is far less versatile). Visual BASIC it took me long time to begin to explore, which eventually I did following readership pressure, but soon found I understood it and appreciated its facilities, resulting in my Toolkit TK3 *software (Nov '01).*

No, I have nothing against BASIC and have never got on with C, but have not needed to explore BBC BASIC again, which I did not know still existed until recently. No reader has ever offered us anything written in a current version.

QB and VB are readily available, though, and on the face of it I can see no justification for adding another dialect to those that we support now. However, if enough readers disagree with me and prove BBC's worth in a large way we could reconsider. We have, though to adopt a certain consistency in the type of projects we publish and facilities needed to implement them.

Richard then came back with:

Not being a reader of your magazine, I hadn't realised that the use of BASIC was an aspect of some of your projects. I can well understand that you would want to standardise on one dialect, although I would have thought Visual BASIC might be a little daunting for many of your readers. There is no doubting its power, though.

I am quite surprised that you weren't aware of the continued existence of BBC BASIC, as the DOS version (BBC BASIC (86) Plus) has been on the market for about 15 years! It was for a long time sold by a company called M-Tec Computer Services (who advertised in some national magazines) but they ceased trading a couple of years ago. Since then it has been available directly from me.

BBC BASIC for Windows is a brand new version which I have been developing for about the last two years, and which was released in October '01. Its principal market is those people who have fond memories of the BBC Micro, but I have tried to bring it up to date and to provide powerful interfaces into the Windows OS, without adding unnecessary complication.

I then asked: how do you promote your version and justify its existence in the face of competition? Which prompted:

My word, you are provocative! I didn't think, in our capitalist society, one needed to "justify" producing a product in competition with an existing one!

Putting to one side whether BBC BASIC for Windows is, in any serious way, competitive with Visual BASIC my justification for its existence is that there are still quite a few people around who learned to program in BBC BASIC, and prefer it to the alternatives. It was, after all, the standard BASIC taught in schools in the 1980s, and I know a few schools still use it even today.

It's wrong to think of BBC BASIC as being associated solely with the BBC Micro/BBC Master; it was also the resident language in the Acorn Electron, Acorn Archimedes, Cambridge Computer Z88 and Amstrad NC100. Machine-specific implementations have been produced for the RM Nimbus, Tatung Einstein, Amstrad CPC 664/6128, Wren Executive, RM 480Z, Victor Sirius and Apple Mac (all but the last supplied by me). In addition there are generic Z80 CP/M and MS-DOS versions. You can read all about the history of BBC BASIC at:

www.rtrussell.co.uk/products/bbcbasic/history.html

But, Richard, in a "capitalist society" there has to be a financial incentive to producing a product that one wants supported. To do so just for the love of it is praiseworthy, but not exactly commercial! And in that vein, we have to cater for a broader picture, for obvious commercial reasons! Similarly, although we love to keep older readers happy, who may well have fond memories of 20 years ago (like myself), we have to consider the needs of the new generations of readers too who have no knowledge or interest in bygone eras, however beneficial the concepts of those eras may seem to those "in the know".

Incidentally, we have a series of articles scheduled which are based around PICAXE devices, a programming system that uses a variant of BASIC in which to write commands. Coming soon, as they say!

SPECTRUM URL

Dear EPE,

I have tried the quoted URL link address you quote in your *Spectrum Analyser* of Feb '02 but I can't get anywhere, just the usual 404 page.

Incidentally, to avoid multiple copies of VB6 runtime the files, including **inpout32.dll**, can be moved to Windows\System folder. I found my system already had them installed.

Peter Hemsley,
via email

*Somehow an extra slash got in after ORG, delete it and you'll get in ok, as I've just proved (**www.foo.tho.org/charles/fft.html**). Doing a search via **www.google.com** on FFT and on Fast Fourier Transform reveals masses of related links as well.*

Yes, the VB runtime files can be moved as you say. We still have to supply them with our VB software, though, for the sake of those who do not already have them (which is a pity as they take up a good 1MB of disk/web space!)

PIC SPECTRUM ANALYSER

Dear EPE,

I've just been reading your *PIC Spectrum Analyser* in Feb '02. Firstly, thanks for raising this subject and for the many excellent projects in *EPE*. I am not a professional pure mathematician, but I have for various reasons been exposed to Fourier Transforms and spectral analysis over the last year or so, both as part of my job and in relation to private projects.

For more information I would refer readers to *Numerical Recipes in C*, 2nd ed., Press W.H. *et al*. Also there is an excellent book, *The Scientist and Engineer's Guide to Digital Signal Processing* available free as PDFs from Analog Devices (**www.analog.com/technology/dsp/training/materials/dsp_book_index.html**) or from the book's home page (**www.dspguide.com**). Many people, myself included, take issue with the Numerical Recipes coding style, in particular that it appears to have been transliterated from the Fortran version of the book (which came first). It is, however, an absolute must-have reference for mathematical and statistical programming, even if you only use the example code as a starting point for your own implementations.

In the source article you cite, Paul Cuthbertson emphasises the importance of the truism that aliasing is a major issue when using Fourier Transforms, whereas your project has no bandwidth-limiting filter on the input.

The Nyquist (or Shannon) Sampling Theorem states that a continuous signal can be properly sampled only if it does *not* contain frequency components above half of the sampling rate. This cut-off frequency is sometimes called the Nyquist Critical Frequency (NCF). If any frequencies above this are present in the input signal they will be aliased to signals below the NCF. e.g. you sample at approximately 100kHz; the NCF is therefore 50kHz.

To prevent gross aliasing errors, you really need to band-limit the input signal with something like an 8th order Chebyshev low-pass filter. Using cascaded Sallen-Key 2nd low-pass components, this could be constructed from a single quad op-amp with a minimum unit gain bandwidth of around 2MHz (something like a MAX4334). This could be retro-fitted to the input of your unit. In addition, it is now generally accepted that the Nyquist criteria represent a worst-case boundary condition, and that practical real-world systems need to use "over-sampling" where, rather than sample at just twice your expected maximum frequency, you would do it at four or more times the peak.

The subject of which type of anti-aliasing filter design to use is also important. I suggested using a Chebyshev due to its steep skirt and because the Spectrum is intended for audio use. If the input was of a different type, say a digital stream with fast rising edges, a Bessel filter might be better because of its softer impulse response. However, sampling at just twice the peak frequency and operating in a narrow band doesn't give much room for manoeuvre, so a compromise would have to be reached. This is a complicated area, as I'm sure you appreciate.

Nick de Smith,
via email

Thanks for the informative comments Nick, which I regret were too long to include in their entirety.

Regarding filters, that would have taken me into a realm higher than I wished to take for this simple circuit, since, as you say, the whole subject of filter types would have been raised. Such matters are more suited to a tutorial type of article than a simple constructional one. However, readers who wish to take things further are recommended to browse via the links you suggest and those that I quoted.

We would be interested to learn how readers use this analyser. One has told us he wishes to use it in connection with astronomical observations, though he did not say in what capacity.

Constructional Project

PIC VIRUS ZAPPER

ANDY FLIND

Can disease be cured electronically? An experimental circuit for zapping viruses.

NOT SO long ago the fascinating story of Dr. Royal Raymond Rife and his Rife Generator was related in the pages of *EPE* (*An End To All Diseases* – April '01 Supplement). This device was supposedly capable of curing many ailments including some cancers, and a large number of Internet sites devoted to it can be found.

However, it was complex and used a special valve similar to an X-ray device, which renders it difficult and possibly dangerous for most home constructors to experiment with. To compound the problem, no-one seems to be sure exactly how it worked, and apparently some of the remaining examples may even be "red herrings'', non-working devices constructed to discredit Dr. Rife during some political skullduggery!

For enthusiasts and experimenters with bio-electronic devices however, Royal Raymond is far from being the only source of interesting ideas. Another prominent worker in this field is Dr. Hulda Regehr Clark, the originator of a design for an electronic "Zapper" which is also claimed to cure most ills, including cancer. This device is very simple and can be built easily by anyone with electronic constructional knowledge, so it can be presented here for readers to try for themselves if they wish.

UNDER COVER

As in Rife's case, there may be some political intrigue in the story of the Zapper. It was originally brought to the attention of *EPE* editorial staff some three years ago through an email from an enthusiast in New Zealand. A copy of this was forwarded to the present author who did not have Internet access at the time.

No details of the device were given but it was stated that they were to be be found in a book entitled *The Cure For All Cancers* by Dr. Clark. At the time this book was listed with other works by her in an American catalogue, so it was suggested that *EPE* might order it via the Internet on the author's behalf. A prompt reply stated that Dr. Clark's books were out of print and no longer available, but something about its tone suggested that further enquiries might be unwise! Being rather fond of life, both the author and *EPE*'s staff dropped the matter.

Since then time and the Internet have eliminated much of this kind of secrecy and an advertisement offering Dr. Clark's books has appeared in a magazine entitled *Nexus*, placed by a stockist in Devon, England, so a copy of the one containing the Zapper circuit was promptly ordered for study.

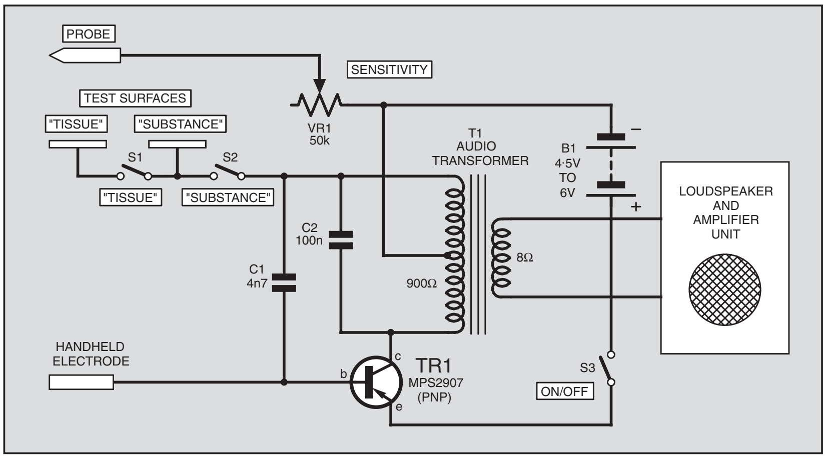


Fig.1. Circuit diagram for the Synchrometer.

Dr. Clark's theory is that all cancers have a common cause and can therefore be cured by the same means. She claims that most people have in their bodies tiny parasites called "Human Intestinal Flukes''. Normally these only live out part of their life cycles within us but the additional presence of a substance called "Isopropyl Alcohol'' in our bodies causes them to remain within us for their cycle. During later parts of this they produce a growth-inducing substance that can trigger cancer. Many readers will know Isopropyl Alcohol as the stuff recommended for cleaning tape recorder heads, but it is apparently present in many other products.

The book also claims that most of us are contaminated by many other toxins, ranging from heavy metals to all kinds of unnatural chemicals originating from substances encountered in modern daily life. Dr. Clark says, obviously enough, that to cure the problem we should get rid of the flukes, stop ingesting isopropyl alcohol and flush out the toxins.

This is a simplified description of the book's main theme and readers wishing to learn more are advised to purchase a copy. The suggested treatment is partly herbal but consists largely of eliminating contact with the contaminants. Since these are contained in a vast array of processed foods and in materials such as plastics and products like shampoo and detergents some dedication would be required to follow the regimen to the letter.

It is also claimed that metals used in dentistry are harmful and should be removed. Whilst one of these is mercury, a highly toxic substance known to cause serious problems for some people, the usual alternative to mercury amalgam fillings is a type of plastic which also meets with disapproval. In short, the options for the true Clark treatment enthusiast are a bit thin.

SYNCHROMETER

However, the book also offers a couple of electronic circuits. One of these is for a device called the Synchrometer, which is claimed to detect the presence of parasites and contaminants within the body. It uses "samples'' placed on two test surfaces, plus a handheld electrode and a probe electrode.

The basic circuit diagram for the Synchrometer is shown in Fig.1. Readers

can decide for themselves whether they feel it would work or not. It has been redrawn for this article since the layout in the book is difficult to follow, to put it mildly.

It appears to be a form of oscillator with the bias current for the transistor passing through the user's body so that variations in body resistance will alter the frequency to some extent. Dr. Clark suggests that the 'quality' of the sound produced by the circuit alters in some way when the contaminant being tested for is present and she refers to this effect as "resonance".

Readers wishing to investigate this area are advised to purchase the book for further details as the procedures given for using this circuit are too complex to be described here.

ZAPPER

The second circuit given is the Zapper, which has generated a great deal of interest. A quick search with one of the Internet search engines will reveal a large number of sites concerned with Dr. Clark and her Zapper and it is even possible to find circuits and construction details amongst these. Since it is easy to construct and use and so many people swear by its effectiveness, it is hard to dismiss the Zapper as "quackery" without putting it to a test.

The Zapper circuit given in the book is shown in Fig.2. It is essentially the standard 555 oscillator circuit, operating at about 28kHz. The user holds two electrodes connected to ground (negative) and the output of the circuit (positive) so that a small current flows through the body, pulsed on and off at this frequency. This treatment is carried out for seven minutes, repeated three times in succession with intervals of twenty to thirty minutes.

The claim is that the first treatment kills the parasites and on dying these release bacteria and viruses, so the second is necessary to kill these and the third kills any remaining viruses released by dying bacteria. The book warns that once the first treatment has been administered it is unwise to miss the two follow-ups as released bacteria and viruses might cause havoc if not subsequently "zapped".

An interesting observation is that the current applied to the body is unidirectional, in that when energized one electrode is always positive and the other always negative. This is the opposite to the recommendation for most bio-electronic devices such as TENs pain-relievers, but the prevailing wisdom seems to be that the Zapper's current flow should be unidirectional. To date the author has not encountered any opinion as to which hand should be positive and which negative, or even if this matters!

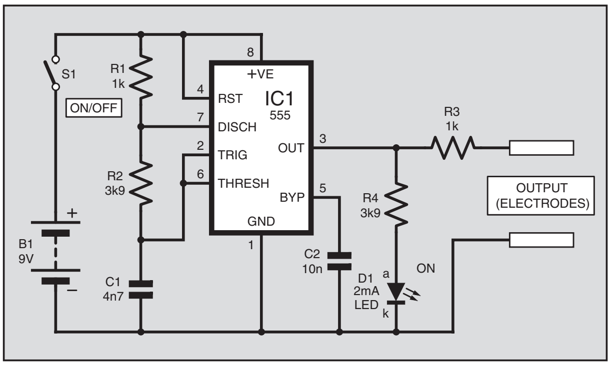


Fig.2. Circuit diagram for the original Zapper.

ORIGINAL CIRCUIT

The original book circuit was tried using a standard 555 timer (IC1) in preference to one of the CMOS variants in case the transition speed of the output waveform was important. The only modifications to the original circuit are shown in Fig.3. These are the addition of a couple of supply decoupling capacitors C1 and C2 and the omission of the l.e.d.

Inclusion of the l.e.d. is supposed to indicate that the circuit is operating but it would not tell the user if a fault caused the output of the 555 to be permanently high! Most *EPE* readers will have better ways to check the output anyway, such as a meter which will indicate somewhere close to half the supply voltage if the circuit is operating, or an

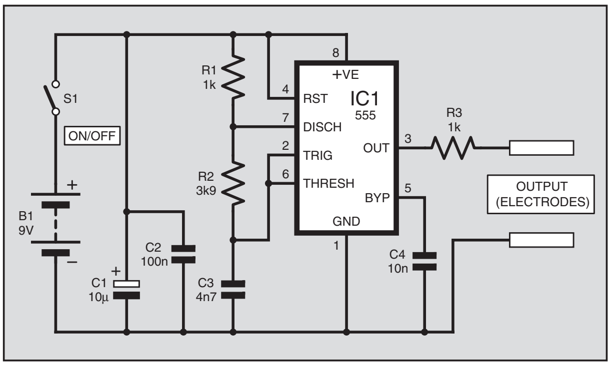


Fig.3. Original Zapper circuit with minor changes.

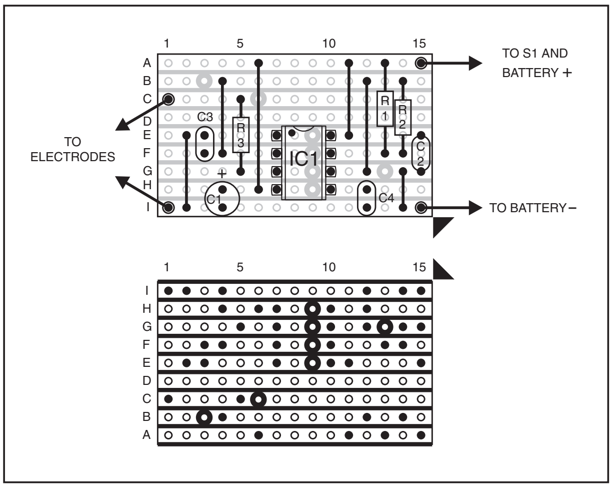


Fig.4. Stripboard construction of the original Zapper.

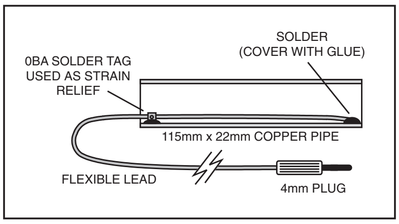


Fig.5. Suggested electrode construction.

COMPONENTS

Modified Original Zapper

Resistors

R1, R3 1k (2-off)
R2 3k9
All 0·6W 1% metal film

Capacitors

C1 10µ radial elect. 50V
C2 100n ceramic
C3 4n7 ceramic
C4 10n ceramic

See SHOP TALK page

Semiconductors

IC1 555 timer

Miscellaneous

S1 s.p.s.t. toggle or slide switch

Stripboard 0·1in. matrix, 9 strips by 15 holes; 8-pin d.i.l. socket; 9V battery (PP3 type); 22mm dia. copper tube for electrodes; solder tags (2 off); solder pins; solder etc.

Approx. Cost Guidance Only £5 excluding electrodes & batt.

Completed PIC-based Virus Zapper together with copper tube electrodes.

oscilloscope for inspecting the output waveform.

The constructional method described in the book involves holes punched in a cardboard box and a lot of wire and croc clips! This is hardly a reliable form of construction so a simple layout using stripboard is shown in Fig.4.

Many constructors will already have the components to hand and will be able to put this circuit together very easily if they wish to simply try the idea. The handheld electrodes can be made from 22mm copper plumbing pipe. The method used by the author is shown in Fig.5. The connecting wire is soldered to the inside of each pipe and an 0BA solder tag soldered inside at the other end is used for strain relief. Some glue spread over the solder connections prevents corrosion.

The electrodes should be wrapped in cloth or paper kitchen towel which has been dipped in water with a small amount of dissolved salt to aid conductivity for a good contact. One of these should be held in each hand and the treatment repeated three times as explained earlier. After use the electrodes should be well rinsed to avoid corrosion due to the salt.

Summary

Enthusiasts for this device claim that it is effective in dealing with most viral infections, some going so far as to claim they haven't had even a common cold in years! Apparently they either 'zap' every few days as a general precaution or they use it at the first signs of a cold or other illness before it has had time to take hold properly. Sounds worth trying at least, but the author is still waiting for the onset of a cold in order to experiment!

NETWORK

A search on the Internet revealed further circuits for the device, some of which represent improvements on the original. One of these is shown in Fig.6 as an example of another circuit which could easily be put together from parts many readers will already have. However, these basic circuits are tedious to use because they involve clock-watching to time both the treatments and the intervals, or operation of a timer of some kind which is awkward when one is holding two electrodes which have been dipped in salt water!

Another design found on the Internet was for a PIC-driven device which provided not only the treatment but also all the timings, which struck the author as a particularly good idea. The purveyor of this circuit also felt that a lower operating frequency of about 2·5kHz was better as it would penetrate further into the user's body tissues.

This is probably so, but there seems to be a considerable body of opinion that the actual operating frequency of the Clark Zapper is relatively unimportant. Since EPE readers deserve only the best a PIC-driven design has been developed for this article and it has to be said that it is a much easier way to try out this form of treatment.

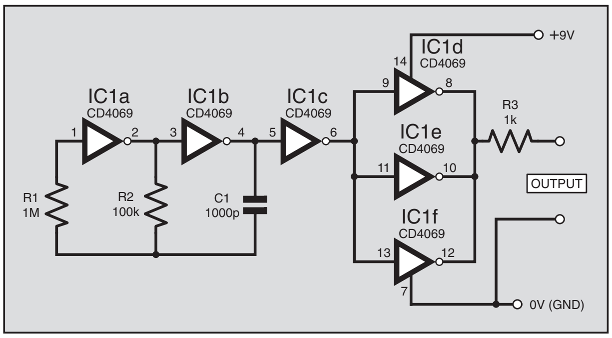


Fig.6. Another Zapper circuit from the Internet.

The status of the unit is indicated by three coloured l.e.d.s. A Yellow one indicates a treatment in progress, a Green one displays for the periods between each treatment, and a Red one warns the user when battery replacement is due. A bleeper indicates the start and end of each treatment, making it easy to use whilst watching TV or during any other occupation for which one normally sits still for an hour or so.

PIC VIRUS ZAPPER

The full circuit diagram for the PIC Virus Zapper is shown in Fig.7. The main supply is provided by a 9V PP3 type battery. This voltage is too high for the PIC (IC2) so it is reduced to 5V by regulator IC1 which is a low-dropout micropower type, better suited for battery operation than the standard 78L05.

The PIC's oscillator uses a 4MHz crystal X1 to give an internal clock of 1MHz. The three l.e.d.s D1, D2 and D3 are low-current (2mA) types driven directly by IC2 through current limiting resistors R3 and R4. Since D2 and D3 are never "on" together they share the common resistor R4.

Bleeps are produced from piezoelectric sounder WD1. This is a type without an internal drive circuit as the author feels it is cheating to use a d.c.-operated type when the PIC can be programmed to generate a squarewave signal for sounder driving!

Battery voltage sensing is carried out by one of the PIC inputs (RB0). This "sees" an input voltage as being either "high" or "low" so preset potentiometer VR1 is adjusted so that it is seen as "low" when the battery voltage falls to about 7V. When this is detected red l.e.d. D1 is turned on.

The Zapper output is controlled by PIC outputs RB4 and RB5 which go high alternately. When RB4 goes high it turns on transistor TR1 which turns on TR2 to pull the output up to full battery supply voltage. When RB4 goes low RB5 goes high to turn on transistor TR3 to pull the output low. This generates a squarewave at the full battery supply voltage from a low impedance, suitable for application through the electrodes. Resistor R9 limits the maximum output current to a safe value if the electrodes are accidentally shorted together.

One further point regarding the circuit is the connection of RA0 and RB7 to the positive and negative supply lines respectively. This is simply for convenience in the physical layout where it enables these voltages to be routed around the printed circuit board (p.c.b.) without the need for "between pin" tracks.

Constructors who make their own p.c.b.s from the magazine artwork will probably appreciate this. One of the many advantages of designing with PIC microcontrollers is that it is perfectly acceptable to do this so long as the pins concerned are designated as inputs by the program.

CONSTRUCTION

Most of the components for this project are mounted on a p.c.b. and the topside layout and full-size foil master are shown in Fig.8. This board is available from the *EPE PCB Service*, code 337.

Assembly should present no real problems for most constructors. An 18-pin d.i.l.

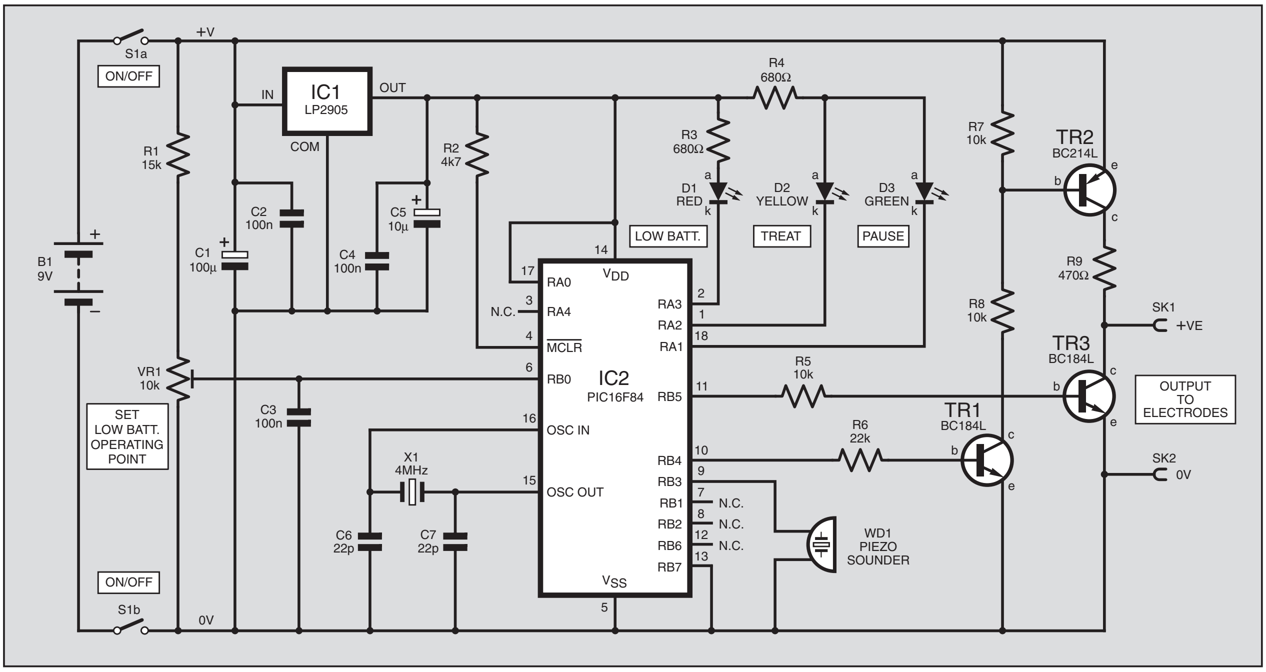


Fig.7. Complete circuit diagram for the PIC Virus Zapper.

COMPONENTS

PIC-based Zapper

See SHOP TALK page

Resistors

R1	15k
R2	4k7
R3, R4	680Ω (2 off)
R5, R7, R8	10k (3 off)
R6	22k
R9	470Ω

All 0·6W 1% metal film

Potentiometer

VR1	10k 22-turn cermet preset, vertical

Capacitors

C1	100µ radial elect. 16V
C2, C3, C4	100n ceramic (3 off)
C5	10µ radial elect. 50V
C6, C7	22p ceramic

Semiconductors

D1	2mA red l.e.d.
D2	2mA yellow l.e.d.
D3	2mA green l.e.d.
TR1, TR3	BC184L *npn* silicon transistor (2-off)
TR2	BC214L *pnp* silicon transistor
IC1	LP2905 5V micropower positive regulator
IC2	PIC16F84 microcontroller, pre-programmed

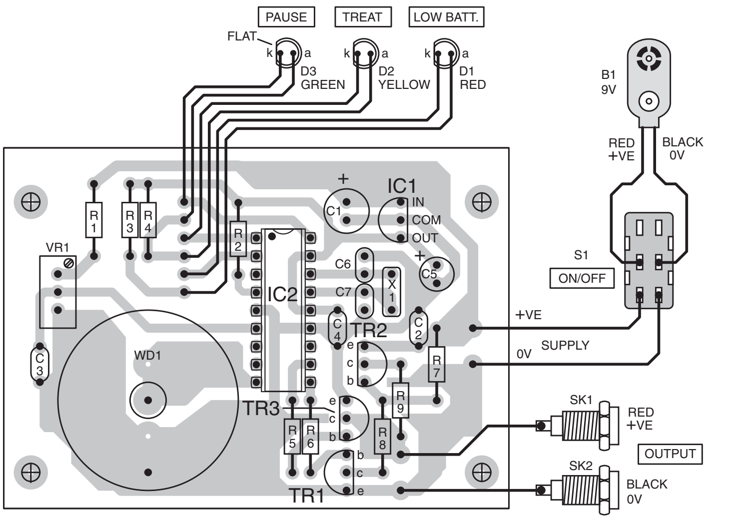
Miscellaneous

X1	4MHz crystal
WD1	piezo sounder, 4kHz
S1	d.p.d.t. slide switch
SK1, SK2	4mm chassis socket and plug (1 red, 1 black)

Printed circuit board available from the *EPE PCB Service*, code 337; case, size 34mm x 80mm x 145mm; 18-pin d.i.l. socket; multistrand connecting wire; 22mm dia. copper tube for electrodes; solder tags (2 off); solder pins; solder etc.

Approx. Cost Guidance Only £22 excluding electrodes & batt.

EPE PIC VIRUS ZAPPER



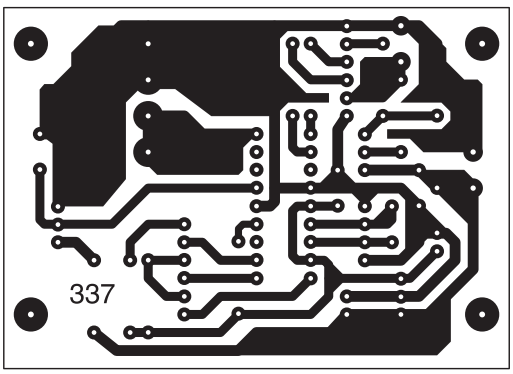
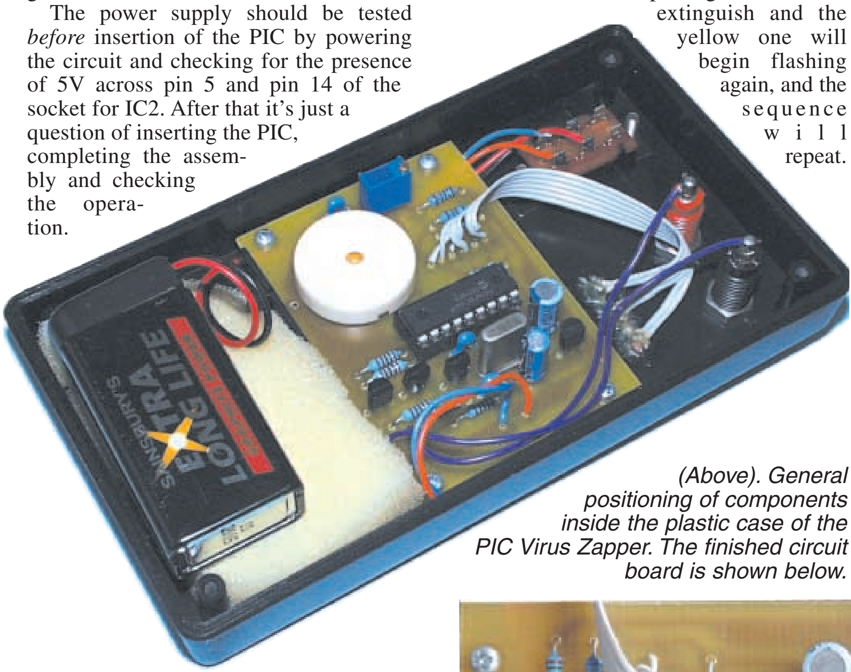


Fig.8. Printed circuit board component layout, interwiring to off-board components and full-size copper foil master pattern. Details of electrode construction are given in Fig.5.

socket is recommended for the PIC, IC2. Two different types of sounder can be used for WD1 so holes are provided to suit the pins of either. The type used should have a resonant frequency of 4kHz as this is the drive frequency used and these devices generate a lot more noise at resonance.

The power supply should be tested *before* insertion of the PIC by powering the circuit and checking for the presence of 5V across pin 5 and pin 14 of the socket for IC2. After that it's just a question of inserting the PIC, completing the assembly and checking the operation.



(Above). General positioning of components inside the plastic case of the PIC Virus Zapper. The finished circuit board is shown below.

ASSEMBLY

The board is designed to fit onto the mounting pillars of a widely available and inexpensive plastic case (with battery compartment) measuring just 145mm × 80mm × 34mm. Interwiring from the circuit board to off-board components is also included in Fig.8. Two robust 4mm sockets are used for the electrode lead connections and the slide switch S1 is fitted for turning the unit on and off.

The three l.e.d.s are connected using a short length of ribbon cable and glued into position. The actual soldering of the ribbon cable to the l.e.d.s should be done as quickly as possible, as one of these failed on the prototype and it seems likely that heat from soldering was the cause.

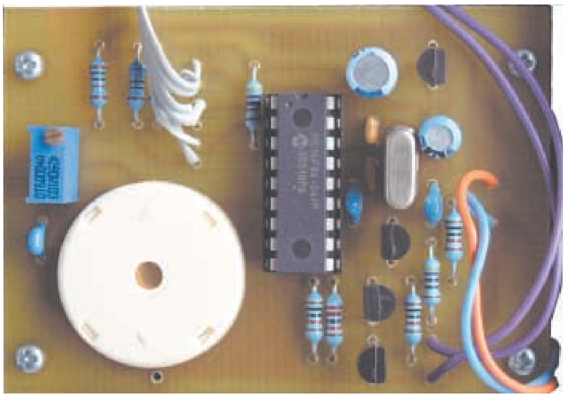
Because the sounder is inside the case its sound is muffled to some extent and it was found that the bleeps could sometimes be missed when watching television. A row of five small holes drilled in the side of the rear half of the case adjacent to the sounder overcame this problem.

SETTING UP

It is necessary to set up preset VR1 to the correct point. If an adjustable power supply is available this can be set to about 7V and VR1 adjusted so that the Red l.e.d. D1 just illuminates.

Immediately following switch-on, the unit should bleep once and the Yellow l.e.d. D2 should flash for thirty seconds. This allows the user to moisten the electrodes and take a firm hold of them before treatment commences. After this there will be another bleep and the Yellow l.e.d. will stay on continuously for seven minutes. During this period the output should be present so a meter across it will read about half the battery supply voltage or an oscilloscope will show the 2·5kHz output squarewave.

Next there will be a further bleep, the Yellow l.e.d. will extinguish and the Green one (D3) will light to indicate the interval between treatments. After 28 minutes there will be a further bleep, the green l.e.d. will extinguish and the yellow one will begin flashing again, and the sequence will repeat.



This should happen once more, but following the third treatment the green l.e.d. should remain on indefinitely and the unit should bleep every five seconds to remind the user to switch off.

Supply current taken by the circuit varies according to the stage reached in the program but the prototype takes about 4mA when flashing l.e.d. D2 and about 7mA plus whatever is delivered through the electrodes (usually about 2mA) when treating, and about 6mA during the intervals. This is small enough to allow a lot of use from an alkaline PP3 battery.

SOFTWARE

The software for the PIC Virus Zapper is available on a 3·5 inch PC-compatible disk from the *EPE* Editorial office, for which a nominal handling charge is made. It is available for free download from the *EPE* ftp site. More details are given on the *EPE PCB Service* page.

Ready-programmed PIC16F84s are being made available to readers by the author. For further details see the *Shoptalk* page.

SUMMING UP

So there you have it, a de-luxe Dr. Clark Zapper as good as any likely to be found on the Internet or elsewhere and certainly much better than the one described in the book! It can be built for a fraction of the price of those available ready-made.

Does it work? American Internet sites offering Zappers all state that they are *not* approved by the FDA (their official government medical body) and are "for experimental use only" but at least their sale hasn't been banned yet.

To date, it's too early for the author to give an opinion one way or the other, but there are a lot of users who praise this little device so it's worth trying. As always with experimental projects of this type, feedback from readers who build and try it will be most welcome as this may eventually prove its worth. □

Further Reading

The Cure For All Cancers – Dr. Hulda Regehr Clark, New Century Press (US). ISBN1-890035-00-9. Melanie Davies, The Cottage, Bovisand Lane, Down Thomas, Devon, PL9 0AE. Phone: 01752 862411 (UK suppliers of Dr. Hulda Clark's books)

Interesting Zapper websites:

www.zapperplans.com/plans.html (circuit of Fig.5, how to construct).

www.drclark.net/disease/zapper.htm more info on Dr. Clark and the zapper.

www.relfe.com/hulda_clark.html (an objective review of Dr. Clark's books).

www.ess-in.com/index.htm (view pictures of two commercially produced zappers).

www.home.att.net/~dennis.shepard/health.htm (another site selling a zapper, pdf file about it).

www.huldaclark.com/BuildZapper.htm (book sales and construction details).

www.zapperplans.com/plans.html (pdf file of a PIC-based circuit, no program given).

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BACK ISSUES

We can supply back issues of *EPE* by post, most issues from the past three years are available. An *EPE* index for the last five years is also available – see order form. Alternatively, indexes are published in the December issue for that year. Where we are unable to provide a back issue a photostat of any *one article* (or *one part* of a series) can be purchased for the same price. Issues from Jan. 2001 onwards are also available to download from **www.epemag.com**.

DID YOU MISS THESE?

NOV '00

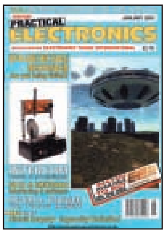
PROJECTS ● PIC Pulsometer ● Opto-Alarm System ● Sample-and-Hold ● Handclap Switch.
FEATURES ● The Schmitt Trigger–Part 1 ● Ingenuity Unlimited ● PIC Toolkit Mk2 Update V2.4 ● Circuit Surgery ● New Technology Update ● Net Work – The Internet ● FREE Transistor Data Chart.

DEC '00

PROJECTS ● PIC-Monitored Dual PSU-Part1 ● Static Field Detector ● Motorists' Buzz-Box ● Twinkling Star ● Christmas Bubble ● Festive Fader ● PICtogram.
FEATURES ● The Schmitt Trigger–Part 2 ● Ingenuity Unlimited ● Interface ● Circuit Surgery ● New Technology Update ● Quasar Kits Review ● Net Work – The Internet ● 2000 Annual Index.

JAN '01

PROJECTS ● Versatile Optical Trigger ● UFO Detector and Event Recorder ● Two-Way Intercom ● PIC-Monitored Dual PSU–Part 2.
FEATURES ● Using PICs and Keypads ● The Schmitt Trigger–Part 3 ● New Technology Update ● Circuit Surgery ● Practically Speaking ● Ingenuity Unlimited ● CIRSIM Shareware Review ● Net Work – The Internet.



FEB '01

PROJECTS ● Ice Alert ● Using LM3914-6 Bargraph Drivers ● Simple Metronome ● PC Audio Power Meter.
FEATURES ● The Schmitt Trigger–Part 4 ● Ingenuity Unlimited ● Circuit Surgery ● New Technology Update ● Net Work – The Internet ● *Free* 16-page supplement – How To Use Graphics L.C.D.s With PICs.

MAR '01

PROJECTS ● Doorbell Extender ● Body Detector ● DIY Tesla Lightning ● Circuit Tester
FEATURES ● Understanding Inductors ● The Schmitt Trigger–Part 5 ● Circuit Surgery ● Interface ● New Technology Update ● Net Work – The Internet Page.

APRIL '01

PROJECTS ● Wave Sound Effect ● Intruder Alarm Control Panel–Part 1 ● Sound Trigger ● EPE Snug-Bug Pet Heating Control Centre.
FEATURES ● The Schmitt Trigger–Part 6 ● Practically Speaking ● Ingenuity Unlimited ● Circuit Surgery ● Net Work – The Internet Page ● *FREE* supplement – An End To All Disease.

MAY '01

PROJECTS ● Camcorder Mixer ● PIC Graphics L.C.D. Scope ● D.C. Motor Controller ● Intruder Alarm Control Panel–Part 2.
FEATURES ● The Schmitt Trigger–Part 7 ● Interface ● Circuit Surgery ● Ingenuity Unlimited ● New Technology Update ● Net Work – The Internet Page.

JUNE '01

PROJECTS ● Hosepipe Controller ● In-Circuit Ohmmeter ● Dummy PIR Detector ● Magfield Monitor.
FEATURES ● Controlling Jodrell Bank ● PIC1687x Extended Memory Use ● Practically Speaking ● Ingenuity Unlimited ● New Technology Update ● Circuit Surgery ● Net Work – The Internet Page.

JULY '01

PROJECTS ● Stereo/Surround Sound Amplifier ● PIC to Printer Interface ● Perpetual Projects 1– Solar-Powered Power Supply and Voltage Regulator ● MSF Signal Repeater and Indicator.
FEATURES ● The World of PLCs ● Ingenuity Unlimited ● Circuit Surgery ● New Technology Update ● Net Work – The Internet Page.

AUG '01

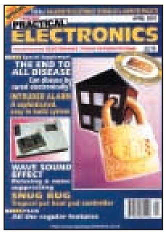
PROJECTS ● Digitimer ● Lead-Acid Battery Charger ● Compact Shortwave Loop Aerial ● Perpetual Projects 2 – L.E.D. Flasher – Double Door-Buzzer.
FEATURES ● Controlling Power Generation ● Ingenuity Unlimited ● Interface ● Circuit Surgery ● New Technology Update ● Net Work – The Internet Page.

SEPT '01

PROJECTS ● Water Monitor ● L.E.D. Super Torches ● Synchronous Clock Driver ● Perpetual Projects 3 – Loop Burglar Alarm – Touch-Switch Door-Light – Solar-Powered Rain Alarm.
FEATURES ● Controlling Flight ● Ingenuity Unlimited ● Practically Speaking ● Circuit Surgery ● New Technology Update ● Net Work – The Internet Page.

OCT '01

PROJECTS ● PIC Toolkit Mk3 ● Camcorder Power Supply ● 2-Valve SW Receiver ● Perpetual Projects 4 – Gate Sentinel – Bird Scarer – In-Out Register.
FEATURES ● Traffic Control ● Ingenuity Unlimited ● New Technology Update ● Circuit Surgery ● Interface ● Net Work – The Internet Page ● *Free* 2 CD-ROMs – Microchip 2001 Tech Library.



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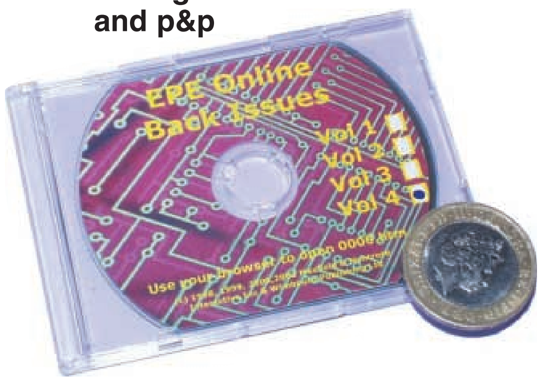

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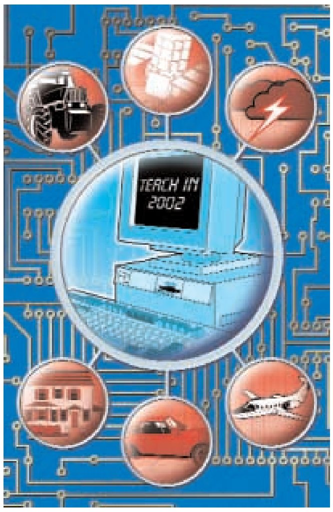


TEACH-IN 2002

Part Five – Taking the Pressure – more on strain, plus accelerometers and pressure sensors

IAN BELL AND DAVE CHESMORE

Making Sense of the Real World: Electronics to Measure the Environment

LAST month in Part 4 we looked at strain gauge sensors and found that we needed to use bridge circuits and differential amplifiers to make effective use of them. Therefore we spent some time looking at the properties of differential signals and bridges, and we investigated the topic of source impedance, which is needed to deal with the possibility of our circuits loading the sensors.

This month we take a more practical look at the same topics and discuss the design of differential amplifiers for sensor applications. We also return to strain gauges and examine some of their various applications. In particular we focus on their application for measuring pressure, and describe a simple weighing machine in Lab Work. First, though, there's more to discuss about op.amps in relation to their use in sensor circuits.

OP.AMP SPECS

In Part 4 we discussed the ideas of differential signals and input impedance and loading in general terms – these concepts relate directly to some important op.amp specifications.

In a real circuit the actual rejection of noise or drift common to both halves of a differential signal depends on how perfect the **differential amplifier** used for this purpose is.

The ratio of (unwanted) output change to common mode input change is called **Common Mode Gain** (A_{CM}, Amplification Common Mode) and the ratio of differential gain to common mode gain is called the **Common Mode Rejection Ratio** (CMRR). CMRR is measured in decibels (dB). A value of 80dB to 110dB is fairly typical for op.amps, but lower and higher values occur (for the OP177 it is 110dB to 126dB.

High common mode gain, and hence poor CMRR, affects gain accuracy in some configurations and determines the ability of the op.amp to ignore noise common to both inputs. Common mode rejection is particularly important in sensor applications where very small differential signals from sensors must be amplified in the presence of noise, or where temperature compensation signals must be accurately dealt with. Sensor applications such as strain measurement often demand high CMRR amplifiers with CMRR values in excess of 100dB.

For an op.amp, **Common-Mode Input Impedance** is the effective impedance between either input terminal and ground, and is ideally infinite. **Differential Input Impedance** is the apparent impedance between the inputs, also ideally infinite.

The input impedances will take the form of capacitance in parallel with resistance. Sometimes the capacitance is not considered and only resistance is quoted. Input capacitances may also be quoted separately. FET-input op.amps have particularly high input resistance (e.g. 10^{12} ohms).

We have to be very careful, though, to distinguish between the input impedance of the op.amp itself and a circuit built using an op.amp. The *circuit* may have a low input impedance even if the *op.amp* has a very high impedance.

DIFFERENTIAL AMPLIFIER PITFALLS

As we have noted, the op.amp is a differential amplifier. However, in order to use it as a practical amplifier we have to apply negative feedback. The most straightforward op.amp-based amplifier circuits (the inverting and non-inverting amplifiers) have a single ended input, but the differential amplifier configuration (Fig.5.1) would appear to suit our purpose – if the op.amp has a good CMRR the circuit seems to provide what we need.

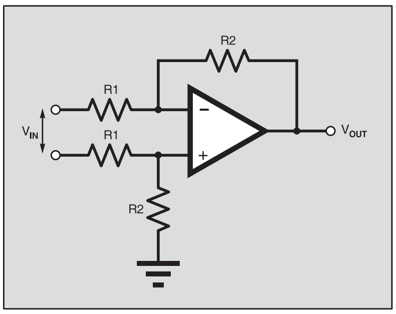


Fig.5.1. Differential amplifier.

Be careful with such assumptions! Good op.amp performance does not guarantee good circuit performance. The CMRR of the circuit in Fig.5.1 is a good example of this as it depends strongly on the matching of the resistor values. The differential gain of the circuit is given by R2/R1 – the design assumes that the two R1 values, and the two R2 values, are exactly the same.

In fact, with an ideal op.amp and exactly matched resistors, the CMRR would be infinite (ideal). With real resistors, however, we get a variation in values which degrades the matching and reduces the CMRR.

For example, consider a typical differential amplifier with a gain of 100 in which R1 is 1kΩ and R2 is 100kΩ. If there is a value difference of 5% between the two R1 resistors, or between the two R2 resistors, then we get a CMRR of only 26dB, even with an ideal op.amp.

For a 1% variation we get about 40dB, for 0·1% about 60dB and for 0·01% about 80dB. So we need some very expensive resistors to get even a half-decent performance from this circuit.

A possible solution is to use a trimmer to vary one of the resistor values until the *common mode gain* is minimized. We only need one trimmer for this as it is the *ratio* of R2 to R1 which is of prime importance. However, this approach is not easy because the trimmer must be very stable and we still need very high accuracy resistors to get good CMRR.

Another problem with the circuit in Fig.5.1 is that it is difficult to adjust the *signal gain* (e.g. using a trimmer or potentiometer) as we have to vary two resistors by exactly the same amount. We could use

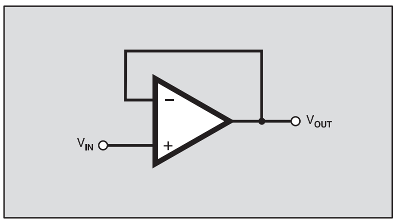


Fig.5.2. Unity gain buffer amplifier.

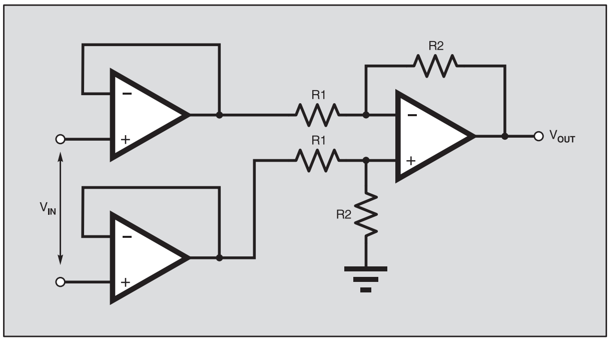


Fig.5.3. Differential amplifier with buffered inputs.

a dual-gang potentiometer, but the matching between the two values is likely to be poor, resulting, as we have seen, in very poor CMRR.

BUFFERING

CMRR and gain adjustment are not the only problem with Fig.5.1 – we also have to stop for a moment and consider another matter of importance that was discussed earlier – input impedance. As we are considering differential signals we need to know the differential input impedance in Fig.5.1. Many sensors have high internal resistance and we therefore require amplifiers with high input resistance in order to use these sensors.

To find the input resistance of the circuit in Fig.5.1 we recall the idea of the virtual short circuit discussed in Part 2. The gain of the op.amp is so high that its two inputs are effectively at the same voltage, or effectively connected together. This is like having the two input resistors connected in series across the differential input, thus the differential input resistance is equal to 2R1.

This input resistance will be quite small compared with the op.amp input resistance. We could try to use high value resistors, but this would impair circuit operation – remember that the op.amp needs bias current and this results in voltage drops across external resistors.

Amplifiers with very large input resistance are called *buffers*. Sometimes these do not have a great deal of voltage gain, but this can be provided by subsequent stages.

For example, the circuit shown in Fig.5.2 has unity gain, but has very high input impedance, particularly if a high input impedance op.amp, such as a FET-input op.amp, is used.

We can combine Fig.5.1 and Fig.5.2 to give a differential amplifier with high input impedance as shown in Fig.5.3. It still has poor CMRR, but it would be useful in situations where we know that any common mode signals are small.

INSTRUMENTATION AMPLIFIERS

To solve the CMRR problem we have to use a different circuit configuration. The key circuit is a two op.amp differential output amplifier as shown in Fig.5.4. The differential gain (differential input to differential output) is given by (1 + 2R2 / R1) and the common mode gain is one (unity). For a more detailed description of this circuit see Panel 5.1.

The circuit in Fig.5.4 has a differential output, but this is easily converted to a singled ended signal using a standard differential amplifier configuration, as shown in Fig.5.5. This circuit is known as an **instrumentation amplifier** (in.amp) as it is so commonly used in sensor and instrumentation systems.

The in.amp (Fig.5.5) overcomes the problems highlighted with the previous circuits. The inputs go straight into the high impedance inputs of the op.amps so the input impedance is high. The large differential gain with respect to common mode gain available from the first stage means that the problem of poor CMRR in the differential amplifier stage is far less severe. The in.amp can achieve very good CMRR.

The gain of the amplifier is easily varied using a single resistor, R1. The resistor (or adjustable preset) should be physically close to the op.amps – using a panel-mounted potentiometer would degrade circuit performance. However, if panel-mounting has to be used, then the wiring should be shielded (screened).

The differential amplifier output stage is usually used with low (e.g. ×2) or unity gain. For unity gain R3 = R4.

It is worth pointing out that the inputs of the circuits in Fig.5.2 to Fig.5.8 cannot be simply capacitively coupled to an a.c. source as the op.amps require a d.c. path for bias currents. A high value resistor (e.g. 1M) must be connected between the op.amp(s) input and ground if a.c. coupling is used. Similarly, a generator sensor such as a thermocouple cannot simply be placed across the differential inputs of Fig.5.2 and Fig.5.3.

OPTIMISING IN.AMPS

In.amps are often used in demanding applications, such as the amplification of low voltage signals from a strain gauge bridge. In order to get the best performance from these circuits great care must be taken in their design and implementation.

Referring to Fig.5.6, which shows an in.amp schematic with some additional details, the following points are important in the design of high precision sensor circuits.

In.amps must be constructed using high quality op.amps with high input impedances, low bias currents, low offsets, and good CMRR. Offsets can be trimmed as shown in Fig.5.6 (by VR1), using just one of the input op.amps (IC1 or IC2). However, if possible, this technique should be avoided by using ultra low offset op.amps.

The CMRR of the differential amplifier stage (around IC3) can be trimmed by balancing the R4/R3 resistor ratios as mentioned previously. To do this, apply a common mode signal and adjust the trimmer (VR2) for minimum output.

The feedback resistors of the output stage of the in.amp are labelled *sense* and *reference* in Fig.5.6. Wiring these terminals directly to the load as shown eliminates errors due to losses in the wiring or external circuitry.

The supply should be capacitively decoupled (ideally for each op.amp), close to the op.amps and with a combination of higher value (say 0.25μF to 0.5μF) and

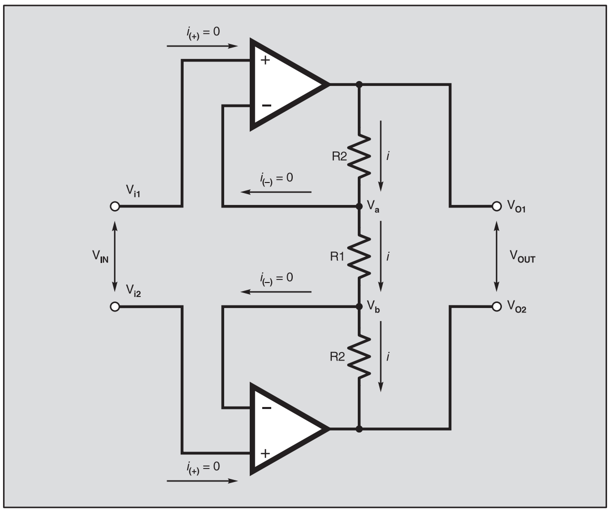


Fig.5.4. Differential output amplifier.

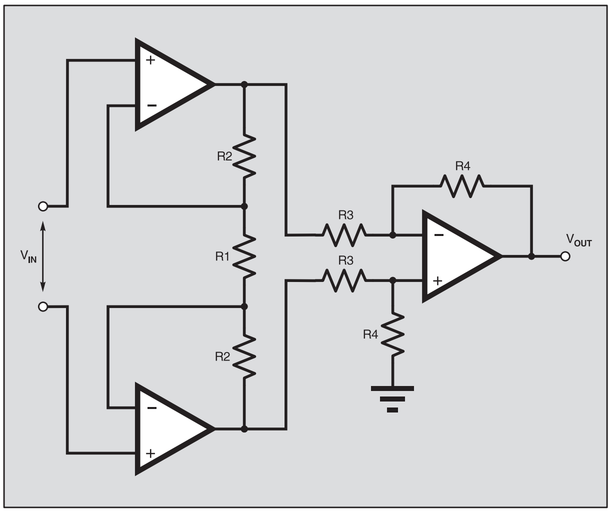


Fig.5.5. Instrumentation amplifier (in.amp).

lower value (say 0.01μF) capacitors. The supply has two rails (+VE and –VE) so you need a set of decoupling capacitors for each (C_{S1} to C_{S4} in Fig.5.6). These suppress power supply noise (that might otherwise find its way onto the output) by bypassing transients.

HIGH QUALITY

To get good performance, high quality plus high accuracy (1% or better) resistors with low temperature coefficients should be used. Errors in high precision circuits can come from unexpected sources. The fact that resistors in different parts of a circuit have on average quite different voltage levels across them, means that their power dissipation, and hence self-heating, can be quite different.

So even if all the resistors have the same temperature coefficient, their relative values can change, resulting in gain errors or other problems. Using resistors having a higher power rating than strictly necessary (as long as they are of equal quality) and using large value resistors can help alleviate this problem.

The in.amp may have very good CMRR at d.c., but not at very high frequencies. Thus radio frequency interference (RFI) picked up at the in.amp input may end up (after rectification by the op.amp internal circuits) as a d.c. error. This can be reduced using an RFI suppression circuit (C1, C2 and R5 in Fig.5.6).

The cutoff frequency (–3dB) of the input filter is given by the usual formula $1/2\pi RC$, where R is the sum of the two resistances and C is the sum of the three capacitances. With 20kΩ resistors, capacitors C1 at 1nF, and C2 at 22nF, the cutoff frequency is around 166Hz.

The resistors and C1 and C2 must be high accuracy (1% resistors and 5% capacitors or better) to prevent unbalancing the input and degrading the CMRR. As well as potential CMRR reduction, the RFI circuit results in higher loading of the source (particularly for low R4 and R5 values) and higher noise (particularly for high R4 and R5 values). It should therefore only be used when needed.

PANEL 5.1. Analysing the In.amp

To analyse the in.amp (instrumentation amplifier) circuit configuration, we assume that ideal op.amps are used, allowing us to use our helpful simplifying assumptions: the op.amp gain is infinite so the two op.amp inputs are at the same voltage (virtual short circuit), and the op.amp input impedance is infinite so the op.amp input current is zero.

First we consider the fully differential amplifier (Fig.5.4) on its own, its (differential) input voltage V_{in} is $V_{i1}–V_{i2}$. The virtual short circuit means that the voltages on either side of R1 are equal to the input voltages, that is $V_a = V_{i1}$ and $v_b = V_{i2}$.

The zero op.amp input current means that all the current in R1, *i*, also flows in the other two resistors. The differential output voltage is equal to the voltage drop across the three resistors. By Ohm's Law this is simply:

$$V_{out} = V_{o1}–V_{o2} = i(R1 + 2R2).$$

We know the voltage across R1 is $V_{i1} – V_{i2}$ so, again using Ohm's Law we find that $i = (V_{i1} – V_{i2}) / R1 = V_{in} / R1$. Replacing *i* in our previous expression for V_{out} with this gives $V_{out} = V_{in}(R1 + 2R2) / R1$. Rearranging this equation gives us the differential gain, $V_{out} / V_{in} = (R1 + 2R2) / R1 = 1 + 2R2 / R1$.

The in.amp simply adds a standard op.amp differential amplifier after the differential output amplifier. The gain of this stage is R4 / R3 so the overall differential gain of the in.amp is $(1 + 2R2 / R1) \times (R4 / R3)$.

Returning to the differential output amplifier, let's see what happens if we apply a common mode signal. For example, if we increase both V_{i1} and V_{i2} by the same amount then V_a and V_b will follow this change due to the virtual short circuit.

The voltage *difference* has not changed, i.e. the voltage across R1 has not changed, so the current through it will remain the same. The *differential* output voltage will not change but output voltages with respect to ground will shift by the same amount as the inputs. Thus the common mode gain of the differential output amplifier is 1 (unity).

Having discussed the fine details of d.c. amplification, let's describe various sensors with which such techniques are required (recall that we discussed strain gauges last month).

ACCELEROMETERS

When an object is in motion and it changes its velocity, it is said to experience an **acceleration**. In many applications, acceleration (or deceleration – slowing down) can be very large and disastrous.

Take, for example, a car travelling at 40kph and hitting a very solid brick wall. The car will stop very quickly and the deceleration experienced by the occupants will be extremely large. If the driver is not wearing a seatbelt his (or her) head will hit the windscreen with the force of about one tonne (1000kg = 2205lb)! This type of rapid deceleration is called a **shock**.

We can work out how much deceleration occurs if we know how long it takes the car to stop. Assume it stops in 0·1s, then 40kph = $11{\cdot}1ms^{-1}$ and the deceleration is 11·1/0·1 = $111ms^{-2}$ or 11·3g. If it takes 0·01s (10ms) then the deceleration will be $1111ms^{-2}$ or 113g! (Remember that 1g is the acceleration due to gravity = $9{\cdot}8ms^{-2}$).

Objects vibrating also experience acceleration and deceleration, the size of which depends on the frequency of vibration and its maximum amplitude. The peak acceleration, *a*, for any object vibrating at a frequency *f* with peak amplitude *x* is given by:

$$a = 4\pi^2 f^{2x}$$

Let's take an example to illustrate this equation. Say we have a pneumatic road hammer and it vibrates at 10Hz. If the end of the hammer moves by 1cm (0·01m) for each vibration, then the peak acceleration that the person operating the hammer experiences is:

$$4 \times \pi^2 \times 10^2 \times 0{\cdot}01 = 39{\cdot}5s^{-2} = 4g$$

How do we measure acceleration? All accelerometers operate on the same basic principle – the **spring-mass** system (which we shall look at in Lab 5.2). Think of a spring connected to a mass, the other end of the spring being anchored. If the entire system is accelerated then the mass pulls away from the anchor point but is kept back by the force in the spring.

As the mass moves further away, the force in the spring gets stronger until the force on the mass (F = ma) equals that of the spring, i.e. they are in equilibrium. It turns out that the distance moved by the mass is proportional to the acceleration, so

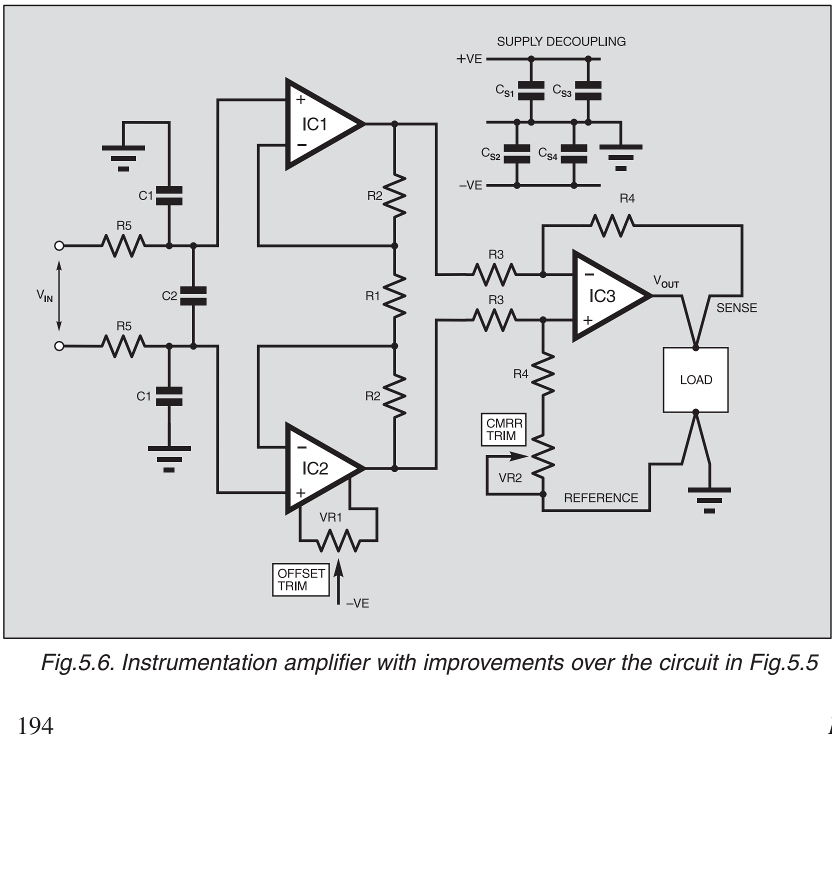


Fig.5.6. Instrumentation amplifier with improvements over the circuit in Fig.5.5

we can reduce the measurement problem to one of measuring distance.

The mass used in accelerometers is called the **test mass** or **seismic mass**. Many modern accelerometers use either silicon strain gauges or a piezoelectric crystal to measure distances. Fig.5.7 shows a device based on a piezoelectric crystal and has the seismic mass held against the crystal by a spring.

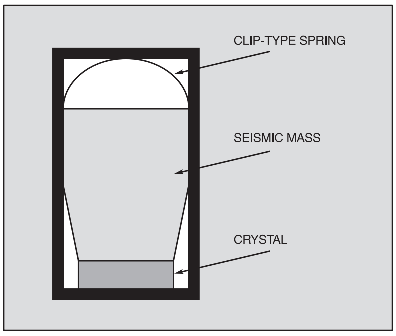


Fig.5.7. Example of a piezoelectric accelerometer.

Modern accelerometers are integrated with digital logic and can produce digital outputs. Analog Devices produce several devices with one and even two axes. A one-axis sensor, the ADXL105 was used in the *Pocket g-Meter* in *EPE* July 2000. This device produces a voltage output proportional to acceleration, whereas the two-axis ADXL202 produces frequency outputs. Unfortunately, accelerometers are expensive devices and we will not be building any Lab Work circuits that use them.

FEEL THE PRESSURE

Pressure is defined as force per area and there are three forms of pressure measurement:

Absolute pressure – pressure measured relative to a perfect vacuum. A common measure of pressure is pounds per square inch *absolute* (psia). An example is barometric (or atmospheric) pressure.

Differential pressure – this is the difference between two measurement points and is often measured in pounds per square inch *differential* (psid).

Gauge pressure – pressure measured relative to ambient pressure, measurement is again in pounds per square inch *gauge* (psig). An example is measurement of blood pressure.

Measurement units for pressure can be a bit confusing since there are several, but all are in the form *force per unit area*.

You may have an old barometer with a mercury column; this measures atmospheric pressure in mmHg (millimetres of mercury). Other older barometers used water instead of mercury, which made them very large and the measurement unit was in inches of water (inH_2O). More modern barometers measure in millibars (mB) or in atmospheres (atm). The SI unit of pressure is the Pascal (Pa).

Table 5.1 gives conversions between the various units. For example, if the weather forecaster says the pressure will be 1030mB then from the table we can work out that this is equivalent to 14·57psi (1038mB = 1·038 Bar).

Table 5.1. Conversions between Different Pressure Units

Unit	*Equivalent*
1psi	51·714mmHg
1psi	27·680inH_2O
1psi	6·8946kPa
1 Bar	14·504psi
1 atm	14·696psi

PRESSURE SENSORS

The basic principle of operation of a pressure sensor is to convert changes in position of a diaphragm into an electrical signal, which is usually carried out using strain gauges.

We can see how this works if we think about an aneroid barometer, which is a sealed metal chamber with a vacuum inside. Changes in atmospheric pressure cause the chamber to change in size and this is converted to movement of a needle. If we place strain gauges on the sides of the chamber then we can measure changes in their resistance and therefore changes in pressure.

This type of sensor is an absolute sensor. Differential sensors also have a diaphragm but instead of a vacuum on one side, that side is connected to a second pressure source. The diaphragm moves according to the difference in pressure between the two sides. A gauge sensor is a differential sensor with one side of the diaphragm open to the air, usually via a small hole.

Commercial pressure sensors use four silicon strain gauges connected in a bridge format (identical to that used in Fig.5.9 of the Lab Work weighing machine). Fig.5.8 shows a cross-section of an absolute pressure sensor which shows the evacuated chamber below the diaphragm acting as the reference.

Pressure sensors are sensitive to temperature and they often have a temperature sensor built in to provide for temperature compensation. Characteristics of one series of sensors from Sensym (now Sensortechnics, **www.sensortechnics.com**) are listed in Table 5.2; these are fairly typical sensors.

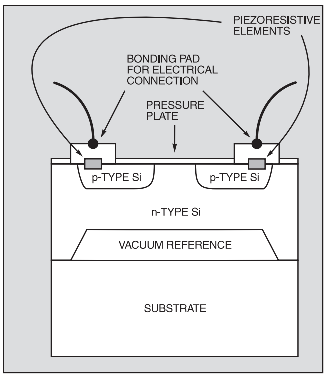


Fig.5.8. Cross-section of an absolute pressure sensor.

In Table 5.2, the column labelled Proof Pressure states the maximum pressure that can be applied without damage.

USING PRESSURE SENSORS

Pressure sensors are expensive (minimum about £18) and need to be treated carefully. Never immerse a sensor in liquid unless it is designed for that purpose. Also, because the silicon wafer complete with gold and aluminium bonding is exposed to the air, any moisture or other liquid present in the air could cause device failure.

A third consideration is the material in the body of the sensor – in some sensors this is stainless steel, which is not a problem, but in others (particularly low cost) the body is plastic. This is not compatible with petrol (gasoline) which may cause the material to soften or dissolve!

ATMOSPHERIC PRESSURE

We have all heard weather forecasters mentioning pressure and seen isobars (lines of equal pressure) on weather maps. Why is air pressure so important?

Firstly, rotation of the Earth and the effect of solar radiation mean that air is not stationary and moves in complex ways in the atmosphere. We often see on weather maps that air tends to circulate around high and low pressure regions and the speed of rotation varies considerably.

Take a hurricane, for example, wind speeds can reach over 100 miles per hour and at the centre of the hurricane is a region of very low pressure. When we see tightly packed isobars on a weather map, we know that it is going to be windy.

Also, there are times when high pressure regions become established when we have clear skies and warm weather in summer, and cold, usually frosty weather, in winter.

High pressure is also associated with interference on television when UHF radio waves become trapped in the atmosphere and travel long distances before returning to the Earth. Under normal conditions, the signals from remote stations will have attenuated sufficiently not to interfere, but under high pressure, they travel much further and cause interference.

LAB WORK

In Lab Work we now perform some experiments using strain gauges.

Table 5.2. Characteristics of Some Sensym Pressure Sensors

Device	*Operating Pressure*	*Proof Pressure (typical)*	*Full Scale Span*	*Temperature Coefficient*	*Input Resistance*	*Output Resistance*
SX01*	0-1psid	20psi	20mV	–2300ppm°C^{-1}	4·65kΩ	4·65kΩ
SX05*	0-5psid	20psi	75mV	–2300ppm°C^{-1}	4·65kΩ	4·65kΩ
SX15**	0-15psid	30psi	110mV	–2150ppm°C^{-1}	4·65kΩ	4·5kΩ
SX30**	0-30psid	60psi	110mV	–2150ppm°C^{-1}	4·65kΩ	4·5kΩ
SX100**	0-100psid	150psi	150mV	–2150ppm°C^{-1}	4·65kΩ	4·5kΩ
SX150**	0-150psid	200psi	110mV	–2150ppm°C^{-1}	4·65kΩ	4·5kΩ

* differential only (SX01D, SX05D)

** These can be absolute (SX15A, etc) or differential (SX15D, etc)

Adapted from **www.sensortechnics.com/dl/sx.pdf**

TEACH-IN 2002 – Lab Work 5

DAVE CHESMORE and ALAN WINSTANLEY

Strain Gauge Weighing Machine

As we saw last month, strain gauges are useful for measuring forces on objects. Here in Lab 5.1 we use two strain gauges attached to an aluminium beam to measure bend due to the weight of an object. The beam is made of 1mm thick aluminium sheet cut to 1cm wide and 8cm long. It is attached at one end to a rigid support as shown in Photo 5.3.

The gauges are placed above and below the beam at about 2cm away from the fixed end. When the beam is bent downwards the top gauge will be extended and the bottom gauge will be compressed. The gauges are placed in a bridge circuit (Fig.5.9) in such a way as to double the voltage change as compared with only one gauge.

You will recall from Part 4 that the change in resistance of a strain gauge is small and the signal needs to be amplified perhaps by 1000 times. The output of the bridge is therefore connected to an instrumentation amplifier (in.amp) built around op.amps IC1, IC2 and IC3. The amplifier has a gain of 1000 set by the ratio of R4 and VR3 as explained in the Tutorial section on in.amps.

The bridge is built around two strain gauges (X1 and X2), resistor R3 and preset potentiometer VR1. In this circuit, R3 is 120Ω since this is the nominal resistance of the strain gauges and VR1 can be varied around this value. X1 is the bottom gauge and X2 the upper gauge.

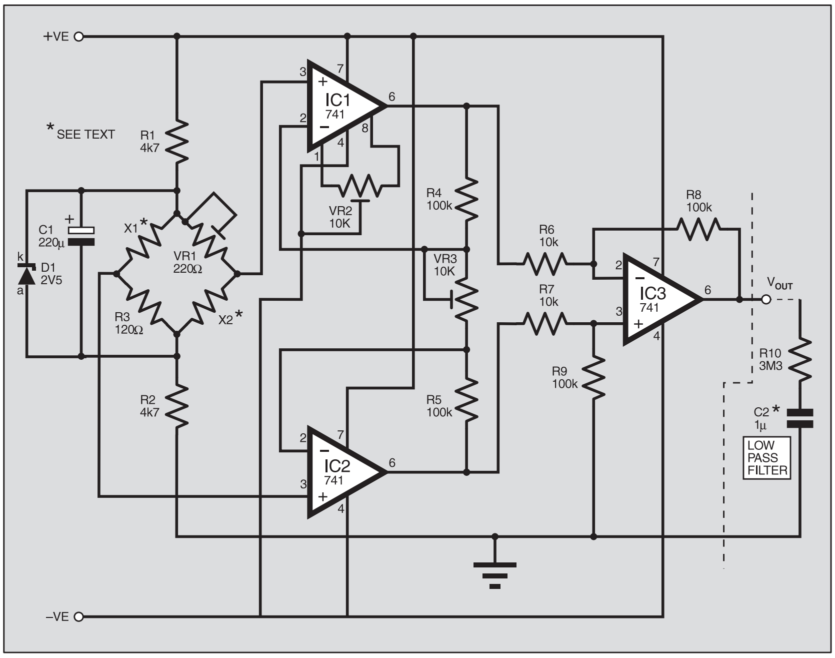


Fig.5.9. Circuit diagram for an experimental weighing machine.

If you use strain gauges that have a different resistance to those suggested in the components list, then make sure VR1 and R3 are the same value as the gauges when they are unstressed. All resistors should ideally be close tolerance, i.e. 2% or 1%.

The bridge needs a stable voltage which is provided by the voltage reference diode D1 (here this is 2·5V but you may use any Zener diode between 2V and 5V). The circuit requires a ±12V supply, which can be provided by the *Teach-In* power supply described in Part 1.

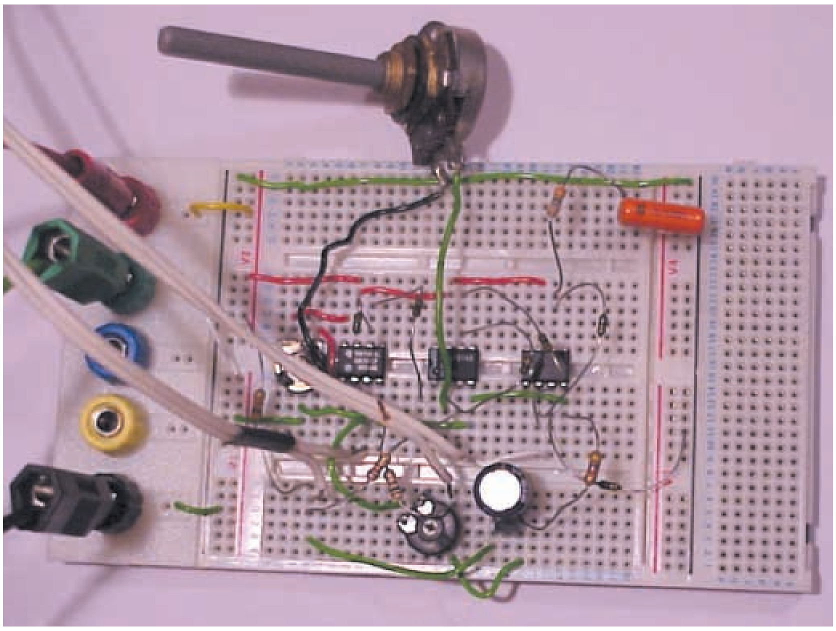


Photo 5.1. Breadboard assembly for Fig.5.9.

CONSTRUCTION

Referring to Fig.5.9 and Photo 5.1, construct the circuit carefully on breadboard. For the moment, omit resistor R10 and capacitor C2.

The strain gauges are delicate and their wires should be soldered to a small section of stripboard. This can be secured to the aluminium strip using Blu-Tack (Photo 5.2). The sensors have a self-adhesive backing allowing them to be fixed firmly to the aluminium, one on each surface.

For our test model, we constructed the support shown in Photo 5.3, but the aluminium strip assembly could equally well be taped securely to the overhang of a work surface.

Attach the wires from the strain gauges, connect all power supply leads and the Picoscope, which should be set to read voltage, and turn the power on.

With no weights on the beam, adjust preset VR2 (offset null) until the output voltage is as close to 0V as possible. You may need to adjust VR1 slightly to accommodate any tolerance variations in resistor R3 and the strain gauges.

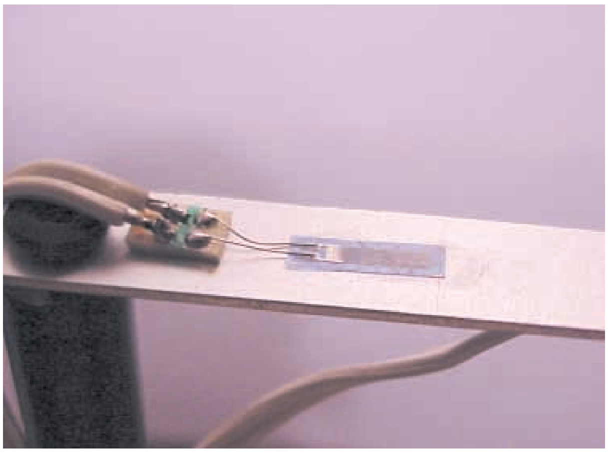


Photo 5.2. Strain sensor assembly.

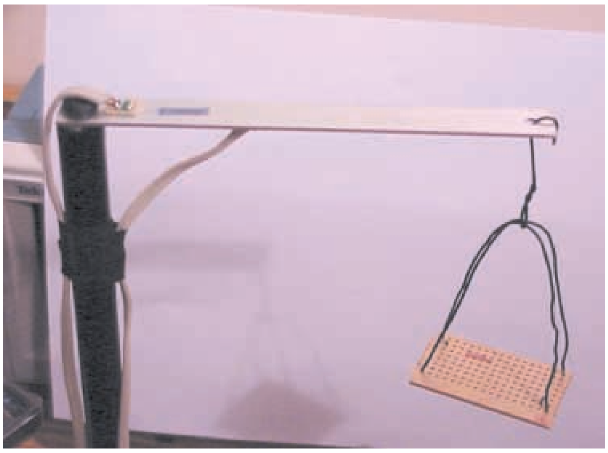


Fig.5.3. Weighing machine support assembly (see text).

Place a weight (e.g. 100g) on the beam (use a hook of wire) and examine the output voltage – it should have changed positively. If it has gone down then swap the wires from the bridge. Potentiometer VR3 allows you to adjust the output to a reasonable value. Change the weight and see what happens; hopefully the relationship between output voltage and weight should be fairly linear!

The circuit can give a good sensitivity, around $10mV/g^{-1}$, and works well for 100g weights and a bit above, but be careful not to bend the beam too far! One noticeable problem with the circuit is a drift in the zero point over time. You could replace the 741 op.amps by OP177s to see if this is improved.

By now including components R10 and C2, you can add a low pass filter that helps to reduce any signal noise.

Lab 5.2 Spring-Mass Oscillation

One of the most familiar physics experiments is to look at oscillations of a mass connected to a spring. In fact, we have seen through the Tutorial that this is the basis of an accelerometer. We can use the weighing machine from Lab 1, together with the Picoscope, to plot changes in force when a mass is attached to a spring.

Attach a spring (any type that will respond to a weight of about 100gms) to the end of the beam of the weighing machine and a weight to the other end. When you pull the weight and release it, it should oscillate for a time before stopping. Use the Picoscope to plot the output voltage.

It might be expected that a nice clean decaying sinewave would be the resulting waveform, but remember that the beam also has a mass and is elastic. Consequently, we get a combination of the oscillations of the beam and of the weight.

Try "twanging" the beam without any weights attached and observing the signal using the Picoscope. However, the amplitude of the beam's oscillation without the weight will be smaller, at a higher frequency and may be difficult to see.

Lab 5.3. The Problem of Noise

When trying to process the signals generated by many forms of sensor, it is important to compensate for the effects of electrical noise and interference that may be picked up along the way. This is especially true when sensor signals are transmitted over long wires, as the accuracy and usefulness of signals can be degraded considerably by noise.

In this Lab Work we demonstrate the basic problems of noise and how to overcome them.

To simulate a remote signal source, a 1kHz 555 square wave generator can be constructed using the circuit of Fig.5.10. This is a completely "floating" circuit that is powered from a 9V battery, with Zener diode D1 limiting the rail voltage to 4·7V. This demonstration should *not* be powered from the *Teach-In* power supply otherwise its "floating" characteristic will not exist.

Construct the circuit of Fig.5.10 on part of your solderless breadboard and monitor

COMPONENTS

Approx. Cost Guidance Only **£30**

N.B. Some components are repeated between Lab Works

See SHOP TALK page

Lab 5.1 and 5.2

Resistors

R1, R2	4k7 (2 off)
R3	120Ω
R4, R5	100k (2 off)
R6, R7	10k 1% (2 off)
R8, R9	100k 1% (2 off)
R10	3M3

All 0·25W 5% carbon film unless stated (see text).

Potentiometers

VR1	220Ω sub-min preset
VR2, VR3	10k sub-min preset (2 off)

Capacitors

C1	220µ radial elect. 16V
C2	1µ polyester

Semiconductors

D1	2·5V reference diode (see text)
IC1 to IC3	741 op.amp (3 off)

Miscellaneous

X1, X2	120Ω strain gauge, 8mm (2 off)

Aluminium strip, 1mm x 1cm x 8cm; beam support (see text); small piece of stripboard (see text); light-duty spring.

Lab 5.3a (Fig.5.10)

Resistors

R1	220Ω
R2	100k
R3	22k
R4, R6	2k2 (2 off)
R5	100Ω

All 0·25W 1% carbon film

Capacitor

C1	10n polyester

Semiconductors

D1	4V7 Zener diode
IC1	555 timer

Miscellaneous

B1	9V PP3 battery

Lab 5.3b (Fig. 5.11)

Resistors

R1	1k
R2	22k

Potentiometer

10k	sub-min preset

Semiconductor

IC1	OP177 or similar op.amp

Lab 5.4

Resistors

R1, R2	1k (2 off)
R3, R4	22k (2 off)

Semiconductor

IC1	OP177 op.amp

Lab 5.5

Resistors

R1	8k25 1% (or 8k2 see text)
R2	43.2Ω 1% (or 47Ω see text)
R3, R4	100k (2 off)
R5 to R8	10k 1%

0·25W 5% unless stated.

Potentiometer

VR1	4k7 sub-mm preset

Semiconductors

IC1	LM334 constant current generator
IC2 to IC4	741 op.amp (3 off)

Miscellaneous

X1	SX100A Sensym 100psi pressure sensor (see *Shoptalk*)

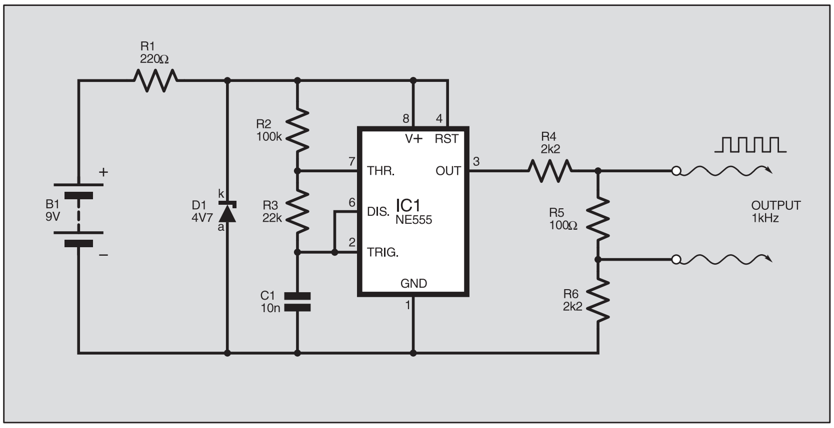


Fig.5.10. Battery operated square wave generator.

the output between IC1 pin 3 and 0V using your Picoscope (see Fig.5.11). Select a suitable timebase, stop the display (space-bar) then click on-screen to place two rulers. The Picoscope display will measure the time period between them – ours was 969μs (f = 1/t so frequency = 1·03kHz).

A simple non-inverting amplifier based on an OP177 op.amp is shown in Fig.5.12. Assemble this on your breadboard, and hook it to the *Teach-In* ±12V power supply.

Connect the op.amp's output and 0V to the Picoscope, and also temporarily connect the wiper of preset VR1 to IC1 pin 3. Vary the potentiometer and observe the output voltage, in order to check that the amplifier is functioning.

By using a very slow timebase and trimming VR1, we obtained results as in Fig.5.13 – note that the Picoscope display will clip the signal at ±5V.

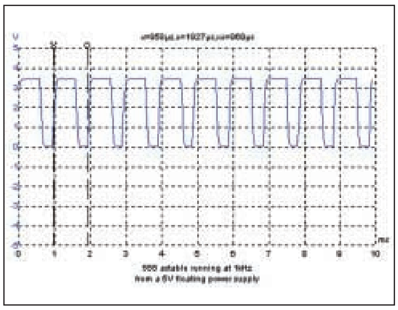


Fig.5.11. Output of Fig.5.10 as monitored by the Picoscope.

Now we need to simulate a signal source connected by relatively long wires. Take two 3-metre (approximately) lengths of general purpose hook-up wire (solid core is better) and twist them together. Simply insert one lead into the 0V rail on the breadboard, close to IC1, and connect the other lead to IC1 pin 3, the non-inverting input.

Observe the Picoscope display (select a timebase of, say, 20ms per division). Our results are shown in Fig.5.14.

Note that although Fig.5.14 apparently indicates a square wave, something else has actually happened. The op.amp has, in fact, amplified the noise that is present on those long wires, which act as antennae, picking up the a.c. electrical signal from the mains wiring all around the building.

A clue is provided in the frequency measurement, which is calculated as 50Hz, as shown, i.e. the UK mains frequency (overseas, you may measure 60Hz). The Picoscope display has clipped the noise signal to just ±5V.

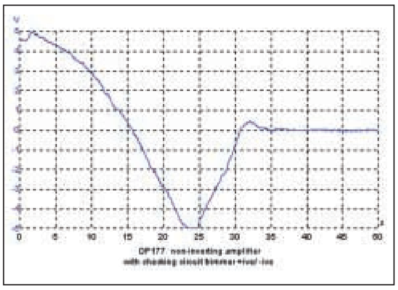


Fig.5.13. Display produced using the circuit in Fig.5.12 when using VR1.

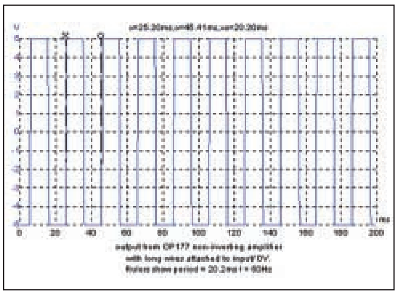


Fig.5.14. Display produced using the circuit in Fig.5.12 when using long wires.

This gives an idea of the scale of the problem facing us when we need to transmit low magnitude signals, e.g. those from a strain gauge, over long wires and amplify them to obtain meaningful results.

The next stage is to connect the 555 astable oscillator in Fig.5.10 as the signal

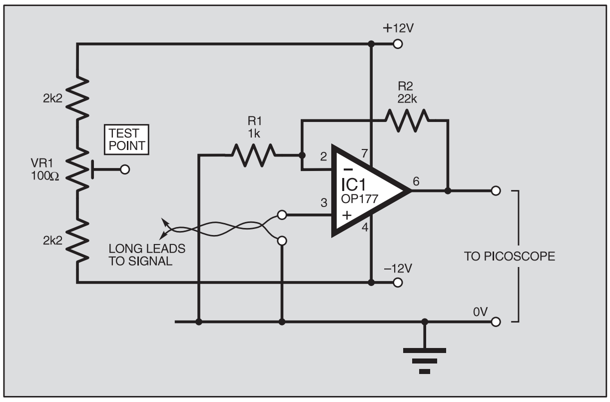
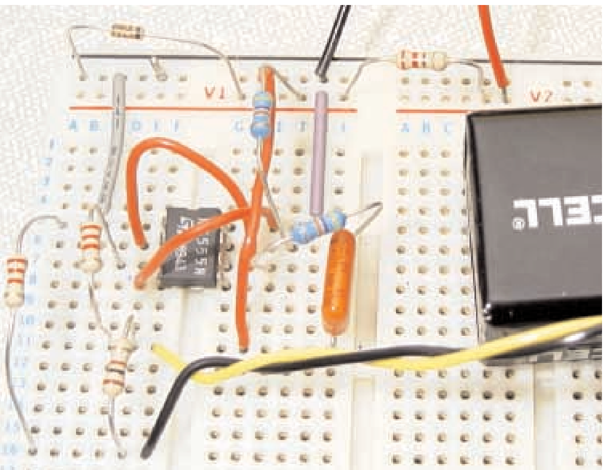
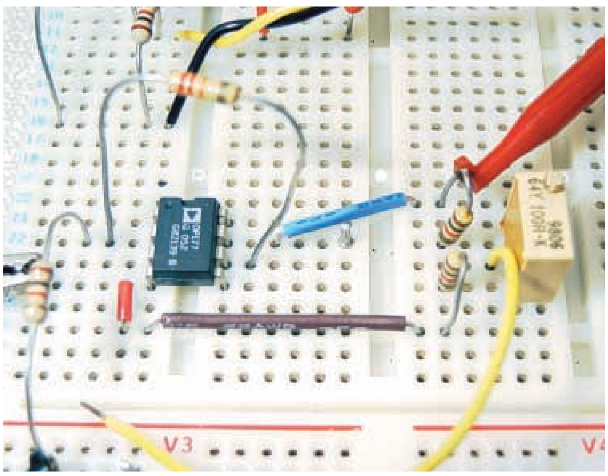


Fig.5.12. Non-inverting test amplifier circuit.



Breadboard assembly for Fig.5.10.



Breadboard assembly for Fig.5.12.

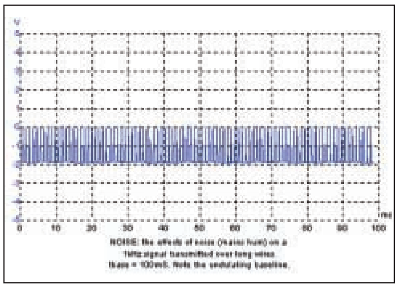


Fig.5.15. Display produced when the circuit in Fig.5.10 is connected to that in Fig.5.12.

source to the op.amp, using the long leads to hook across the 100Ω output resistor (R5). Thus we simulate a sensor's electronic signal of approximately 100mV magnitude being transmitted to an amplifier. Observe the Picoscope display. Fig 5.15 confirms a reading of about 1kHz.

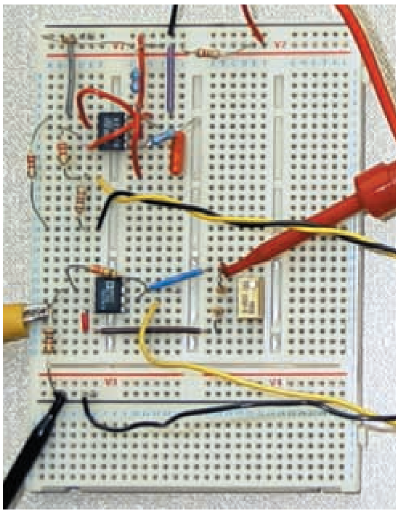
Although the problem of noise is less evident in this simple demonstration, it is still very much there, especially when sensor wires extend for many tens of metres or more. Designers must be mindful of this and the steps needed to "design-out" such problems by using differential amplifiers instead.

Experiment further, if possible, by using extremely long wires, or if you have a reel of it available, compare the use of screened leads or twisted wires. Try to route the wires near to "noisy" electrical loads, such as motors or mains transformers.

Next month we discuss noise in more detail and at the end of *Teach-In* series we will demonstrate a simple radio-frequency system that offers an alternative way of monitoring the environment without the need to use long wires.

Lab 5.4. A Differential Approach to Noise

In Fig.5.16 is shown a simple differential amplifier that can be assembled on breadboard using an OP177 or similar op.amp. Use VR1 from Fig.5.12 to apply a test d.c. voltage to each input in turn; temporarily ground the other input to 0V with a link wire. This time the output will tend to saturate either high or low when the trimmer is adjusted.



Breadboard assembly for Fig.5.10 and Fig.5.12.

The 555 oscillator is again used as a floating signal source and this should now be connected across the two differential inputs of the amplifier by using the two long wires. The op.amp can be monitored again using the Picoscope, see Fig.5.17.

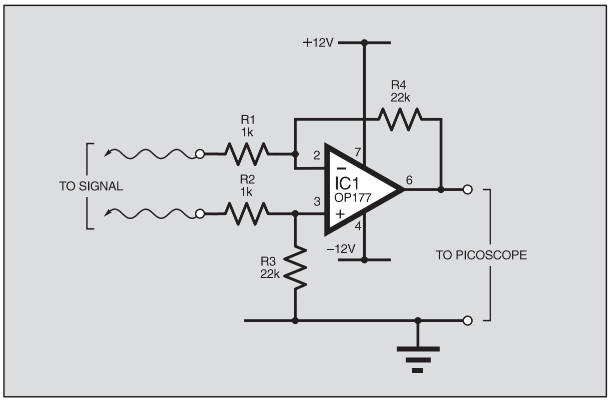


Fig.5.16. Differential amplifier test circuit.

This time we observed that there was much less tendency for the signal to be affected by outside interference from mains hum. Using a differential method like this is clearly likely to ensure that signals from sensors will not be unduly affected by outside sources of noise, hum, electrical spikes and so on.

Other measures that may need to be taken include the appropriate use of shielding and screening, both of the wires themselves and sometimes the measuring equipment and apparatus as well.

Lab 5.5. Atmospheric Air Pressure Sensor

The circuit diagram in Fig.5.18 is for an atmospheric pressure sensor that measures 950mB to 1050mB and uses a Sensym SX100 absolute pressure sensor with a pressure range of 0 to 100psia.

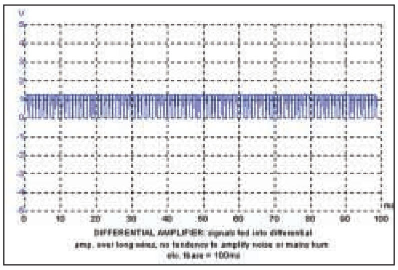


Fig.5.17. Display produced using the circuit of Fig.5.16 with that in Fig.5.10.

Before examining the circuit, we need to work out the overall gain required, given the sensitivity of 1mV per psia. Looking at Table 5.1, 1 Bar is equal to 14·504psi, so 1mB equals 0·014504psi and 1psi equals 1/0·014504 = 68·95mB. Since the SX100 has an output of 1mV per psi then a gain of 68·95 will give an output such that 1V represents a pressure of 1000mB. The output from the circuit in mV can therefore be read in mB.

As the SX100 sensors are temperature sensitive they need a temperature compensation circuit. This can be achieved in a number of ways, including thermistors, diodes and transistors. The method used here is taken from the SX series datasheet from Sensortechnics (**www.sensortechnics.com**) and uses a constant current source device, type LM334 (IC1 in Fig.5.18) which is temperature sensitive.

The resistor values for R1 and R2 have been selected from Table 2 in the LM334 datasheet to give the best temperature compensation for a power supply voltage of 12V. They should be 1% tolerance, although the nearest E12 or E24 series values can be used instead.

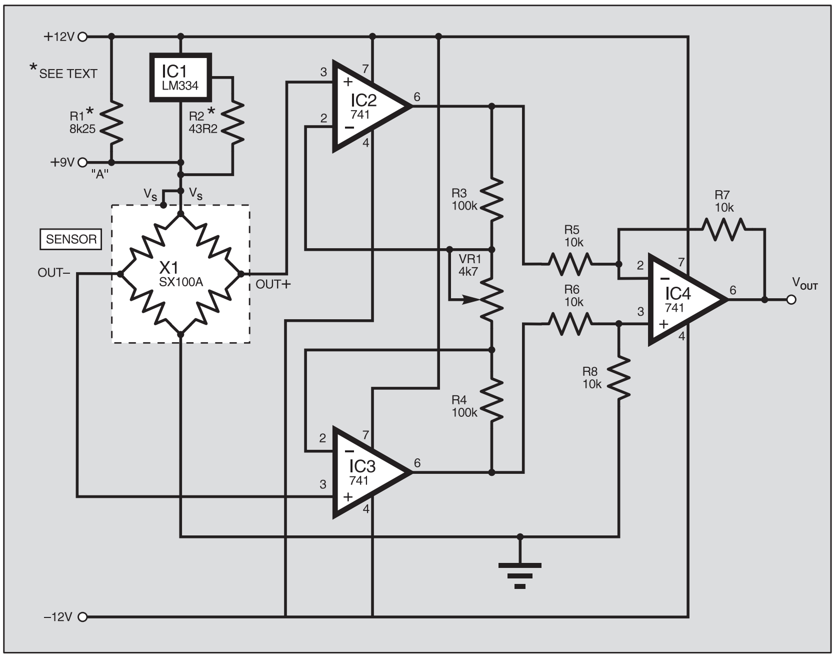


Fig.5.18. Circuit diagram for an experimental air pressure sensor.

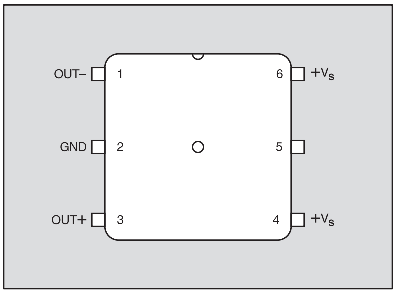


Fig.5.19.Pinout for the SX100 pressure sensor.

It will be seen that the sensor (X1) is represented as a bridge-constructed device, whose respective outputs feed into op.amps IC2 and IC3, the first stage of an in.amp. The second stage of the in.amp is formed around IC4 and is a differential amplifier. The overall gain of the in.amp is between 60 and 80, variable by potentiometer VR1.

Construct the circuit on breadboard, see Photo 5.4. The pinouts for the sensor are shown in Fig.5.19.

The circuit should be powered at ±12V. Following switch on, the bridge supply voltage at test point A should be 9V. Monitor the output of the amplifier and vary VR1 until the output is close to 1V. If it is negative then swap the Out+ and Out– connections from the sensor.

Calibrating the sensor is not very easy unless you have access to a pressure source or a digital barometer. A wall-mounted aneroid barometer is not accurate enough. There are, however, occasions when the weather conditions are very stable, usually during a period of high pressure. When this occurs, the pressure is usually mentioned on weather forecasts and the circuit calibrated by varying VR1 until the output in millivolts reads the pressure in millibars.

One thing to note – air pressure also varies as a function of height above sea level, decreasing with altitude. The circuit we have described here is not compensated for altitude!

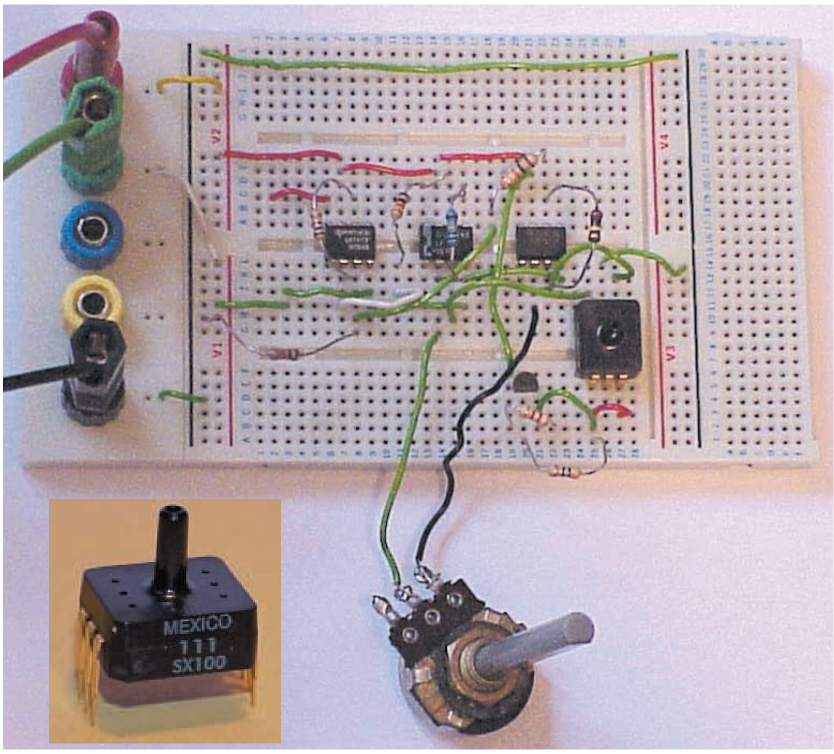


Photo 5.4. Breadboard assembly for the circuit in Fig.5.18, with the inset at the left showing a close-up of the SX100 pressure sensor.

NEXT MONTH

In Part 6 next month we examine noise in more detail, plus magnetic fields and how to sense them.

If you have any queries directly related to this series, you can write to the authors c/o the Editorial address, or you can email them to **teach-in@epemag.demon.co.uk** (no file attachments or general electronic queries please).

SHOP TALK
with David Barrington

MK484 Shortwave Radio

We can give you two sources for the MK484 radio chip used in the *MK484 Shortwave Radio* project. ***Rapid Electronics*** (☎ ***01206 751166*** or ***www.rapidelectronics.co.uk***) list the MK484 as code 82-1026 and it is supplied with a useful data sheet. They also list a suitable miniature (ZN414 type) tuning capacitor, code 12-0250, and a 100mm length ferrite rod, code 88-3098. The other supplier of the 3-pin radio i.c. is **ESR** (☎ ***0191 251 4363*** or ***www.esr.co.uk***), who list it as just MK484. The tuning capacitor is listed by them as code 896-110.

The remaining parts for the SW receiver should be readily available from most of our components advertisers.

PIC Virus Zapper

A pre-programmed PIC16F84 microcontroller for the *PIC Virus Zapper* can be purchased from the author for the sum of £6 (add £1 for overseas). Orders (mail only) should be sent to **Andy Flind, 22 Holway Hill, Taunton, Somerset, TA1 2HB**. Payments should be made out to *A. Flind*. For those who wish to program their own PICs, the software is available from the Editorial offices on a 3·5in. PC-compatible disk (*EPE* Disk 5), see *PCB Service* page 219. It is also available Free via the *EPE* web site: **ftp://ftp.epemag.wimborne.co.uk/pub/PICS/VirusZapper**.

The 4kHz resonance piezoelectric sounder (code 172-7295) and the plastic case (code 244-8577) used in the model both came from RS and can be ordered through any *bona-fide* stockists, including many of our advertisers. You can order direct (credit card only) from **RS** on ☎ ***01536 444079*** or at ***rswww.com***. Expect to pay a post and packing charge.

The printed circuit board is available from the *EPE PCB Service*, code 337 (see page 219).

RH Meter

We understand that the Honeywell HIH3605-A capacitive humidity sensor called for in the *RH Meter* project is stocked by **Farnell** (☎ ***0113 263 6311*** or ***www.farnell.com***), code 723-4624, and by **RS** (☎ ***01536 444079*** or ***rswww.com***) code 334-2975. A post and packing charge may be incurred.

The rest of the components for this project should be easy to find, but being mostly surface mount types you will probably have to order in multiple quantities. If you have difficulty locating surface mount versions of the LM2931 and LM2904 try Farnell, see earlier. The small surface mount printed circuit board is available from the *EPE PCB Service*, code 338 (see page 219).

PIC Mini-Enigma

The 2-channel 20-character alphanumeric display module used in the *PIC Mini-Enigma* project appears to be widely stocked. However, they do seem to vary in price and their interconnecting arrangements, having data/segment wiring pads on the side, top or bottom edges of the p.c.b., and you will need to adapt the wiring to the display. The l.c.d. must incorporate a HD44780 controller chip. (The type in normal widespread use.)

This project requires two PIC16F84s, one for Enigma and the other for the "Matchbox" unit. A pair of ready-programmed PICs can be purchased from **Magenta Electronics** (☎ ***01283 565435*** or ***www.magenta2000.co.uk***) for the inclusive price of £11.80 (overseas add £1 p&p). The software is available on a 3·5in. PC-compatible disk (*EPE* Disk 5) for the sum of £3 (UK), to cover admin costs (for overseas, see page 219). It is also available *Free* from the *EPE* web site at: **ftp://ftp.epemag.wimborne.co.uk/pubs/PICS/Enigma**.

Teach-In 2002 – Lab 5

This month's *Teach-In 2002 – Lab Work 5* needs two special sensor transducers. The strain gauge came from **Rapid** (☎ ***01206 751166*** or ***www.rapidelectronics.co.uk***) and is their type 23 (for aluminium), code 78-1110. Unfortunately, the Sensym SX100A pressure sensor appears to be unavailable at the time of going to press. **Farnell** (☎ ***0113 263 6311*** or ***www.farnell.com***) can supply an alternative SX15A (order code 674-217) which can be used if the gain of the circuit is changed to 10.

PLEASE TAKE NOTE

Time Delay Touch Switch *Jan '02*

Page 26, Fig.2. Note that the p.c.b. foil master should be a "mirror image" (flipped-over) of that shown, i.e. viewed from other side.

PIC Spectrum Analyser *Feb '02*

The RS part number for the TDA703 analogue-to-digital converter should be 181-9754.

Toolkit TK3 *Nov '01*

Update version V1.2 is now on the FTP site, file **07Jan02 TK3 updates.TXT** details the enhancements.

PRACTICALLY SPEAKING

Robert Penfold looks at the Techniques of Actually Doing It!

ONE of the low-tech aspects of this hi-tech hobby is the wire that can be found in every project. Modern construction techniques have reduced the amount of hard wiring, but every project includes at least a few wires and cables. Many projects are fairly bristling with them.

The subject of cables is perhaps slightly more hi-tech than one might think. Looking through one of the larger electronic component catalogues will probably reveal many pages of wires and cables, with dozens of different types listed. For newcomers this may be surprising, but there is no universal cable that suits all eventualities. A cable that is perfect for a television aerial down lead is not much use for wiring up projects, and vice versa.

Hard Wiring

One type of wire every constructor needs is connecting wire, which is also called hook-up or equipment wire. Whatever you call it, this is a thin wire having plastic insulation, and it is used for making the connections from circuit boards to controls and sockets, or any wiring of this general type. There are usually several types on offer in electronic component catalogues.

There are two basic types, which are the single and multi-core varieties. The single core type has the advantage that it can be formed into complex shapes, and it will retain those shapes. This makes it easy to run the wire neatly from point *A* to point *B*. It also makes it easier to form several wires into what is effectively one multi-way cable.

However, single core connecting wire is little used in practice. Its major flaw is that the wire is easily damaged when the plastic insulation is stripped away. Even using proper wire strippers, there is a risk of the wire being nicked slightly. This tends to seriously weaken the wire at that point, usually causing it to break if there is any flexing of the wire. While wire having multiple cores is not immune from this problem, it is much less vulnerable to it.

Making the Grade

Both types of equipment wire are produced in light-, medium-, and heavy-duty varieties. Light-duty equipment wire is usually described as something like "10/0·1", which means that it has 10 strands of 0·1mm diameter wire. This type of wire can only be used for currents of up to about 500mA, but the maximum current in most projects is only a fraction of this figure.

However, a medium duty wire such as a 7/0·2 type is probably better for general project wiring. The maximum current rating for this type of wire is about 1·5A.

An even heavier gauge is needed for projects such as power supplies and power amplifiers, which often involve maximum currents of several amps. Heavy-duty 24/0·2 wire can handle currents of up to 6A and is adequate for most purposes. Heavy-duty equipment wires are unwieldy and difficult to use. Only use a wire of this type where high currents are involved.

Single core equipment wire is generally available in only a limited range of sizes. In fact, these days most catalogues only list one size, if it is included at all. The most common size is 1/0·6, which is suitable for light and medium duty applications.

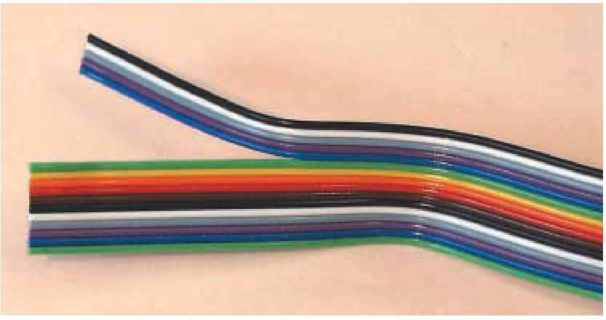


Fig.1. Ribbon cable peels apart to produce a cable having the required number of ways (wires). The ribbon cable shown here is the multi-coloured type.

There are other types of single core wire, and most catalogues list enamelled copper wire in a range of sizes. This type of wire has a very thin layer of insulation that is more or less just a coat of varnish. Wire strippers are not needed with enamelled wire, and the insulation can be scraped away using a miniature file or a penknife.

Enamelled wire is unsuitable for most applications because of the ease with which the insulation is damaged. The main application for enamelled copper wire is home-made inductors (coils) and transformers. Tinned copper wire has no isolation, and is mainly used for link-wires on circuit boards.

Originally, single core wires were available in a range of standard wire gauges (s.w.g.). The available gauges ran from about 14 to 40. These gauge sizes were apparently used for all sorts of things, including knitting needles.

You may still encounter references to something like 24s.w.g. wire, or even 24a.w.g. (American wire gauge). However, the more normal method these days is for the diameter of the wire to be given in millimetres. For instance, 14s.w.g. wire is very thick at about 2mm in diameter, and 40s.w.g. wire is very fine at a mere 0·125mm.

Ribbon Cable

Ribbon cable is a multi-way type that has numerous insulated wires laid side by side and joined together. This produces a flat ribbon-like cable that usually has from 10 to about 60 wires.

One type of ribbon cable is specifically designed for use with computer connectors that utilise solderless connections. The 0·05in. pitch of the wires matches the pitch of the terminals on the connectors. This cable is grey in colour apart from a red lead at one edge. By convention, the red lead is used to connect pin 1 of one connector to pin one of the other connector.

A second type of ribbon cable is of more use when building electronic projects. It is essentially the same, but the wires have insulation of different colours. The colour of the insulation may seem to be of no importance, but it enables each wire to be easily identified.

The idea is to use ribbon cable instead of a conventional cable-form produced from individual wires. This type of ribbon cable is normally sold in 10-way and 20-way varieties, but it is easy to peel off a section having the required number of wires (see Fig.1).

Cross-talk

Ribbon cable provides an easy way of making multiple connections from a circuit board to off-board components such as sockets and potentiometers, but it is best not to merge too many connections into one group. A capacitor consists of two metal electrodes separated by a layer of insulation. A ribbon cable consists of pairs or wires separated by a layer of insulation, and each pair or wires therefore form a capacitor.

The capacitance from one wire to the next is not very great, and will normally be no more than a few picofarads. However, this can still be enough to couple a signal from one wire to the next.

With something like three wires running from a circuit board to a potentiometer, the capacitance in the cable is likely to be too small to have any detrimental effects. Using a four-way ribbon cable to carry the connections to an input socket and an output type is more dubious. This tends to couple some of the output signal

back to the input, which usually guarantees instability. If in doubt, use a separate piece of cable for each component, which is often the easiest way to do things anyway.

Screened Leads

Component catalogues usually list many other types of multi-way cable, and some of these are for specific purposes such as mains leads and RS232C serial cables. Novice constructors are unlikely to use any of these. However, the various types of screened cable are a different matter.

Screened leads are used for audio cables such as the ones used to connect hi-fi components together. The problem with long audio cables is that electrical noise tends to be picked up

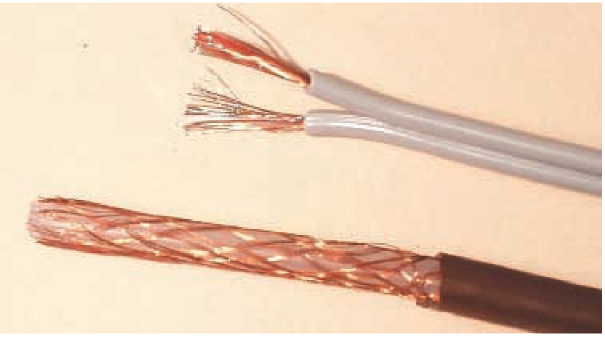


Fig.2. Twin lapped audio cable (top) and 75 ohm coaxial cable (bottom).

in the wires. Mains "hum" is the primary problem, but these days most environments are polluted with electrical noise from radio stations, television sets, etc.

A single screened cable has an insulated wire at its centre, and this is surrounded by some form of screen. In the case of an audio cable, this is usually a number of fine wires that are wrapped around the insulation of the inner wire. This is known as a lapped screen. With some audio cables and many cables that are designed for high frequency use, the wires are woven into a braiding (or mesh).

The lower cable in Fig.2 is a coaxial cable for high frequency use, and this has a simple form of braided screen. The upper cable is a twin audio type and this has a lapped screen. In either case, an overall plastic sheath insulates the screen and holds everything together.

The screen always carries the earth or common (0V) connection, and it provides a barrier between the inner conductor and the outside world. This prevents electrical noise from reaching the inner conductor, or any signals making the trip in the opposite direction.

Audio projects usually have metal cases that are earthed to the negative supply rail, and provide overall screening of the components and wiring. However, under some circumstances it is still necessary to use

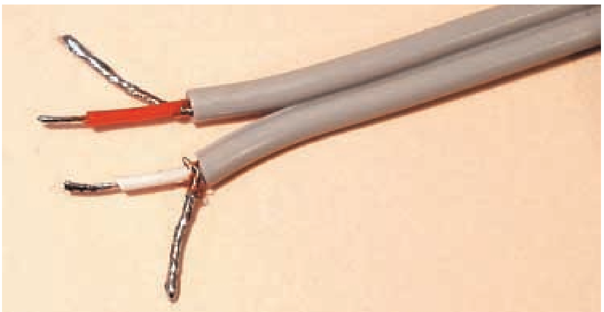


Fig.3. A twin screened (lapped) cable prepared for connection.

screened leads within a project. One reason is simply that the input of the circuit is so sensitive that it becomes a case of the more screening the better.

A more common reason is that the circuit provides a very high level of voltage gain, and that even a minute amount of stray feedback from the output to the input could cause instability. This usually manifests itself in the form of the circuit breaking into oscillation. Using screened leads to carry the input and output connections helps to minimise any stray feedback.

Seeing Double

Audio cables usually carry stereo signals and require twin screened lead. One type is effectively just two single screened leads joined side by side (see Fig.2). This is the best type, since the inner conductors are screened from each other as well as the outside world.

Individual screening virtually eliminates any stray coupling from one lead to the other, which could otherwise reduce the stereo channel separation. The cheaper type has an overall screen for the two inner conductors, but no screening between them. It is best to restrict the use of overall screened cables to applications that require short cables.

Audio cables tend to differ in terms of their quality rather than in any fundamental electrical difference. Cables for operation at high frequencies are different in that they are designed to operate with sources and loads having a certain impedance.

These are generally called coaxial (or just "coax") cables, although strictly speaking, all screened cables are of the coaxial variety. Where a project requires a specific type of screened cable, such as a low-noise audio type or a 75-ohm coaxial cable, the article concerned should explain the exact requirements.

Making Connections

Using screened cables is a bit fiddly, but it is not too difficult. The first task is to remove a piece of the outer sheath from one end of the cable. Ordinary wire strippers work well with thin audio cables, but a special heavy-duty type is required for most coaxial cables. Alternatively, a modelling knife can be used to make two cuts through the sheath on opposite sides of the cable, so that the sheath can be peeled back and trimmed. Either way, try not to damage the fine wires in the screen.

With a lapped cable the wires in the screen can be pulled to one side and twisted together to form a short lead. It is best to tin the wires with solder so that they cannot splay apart again. Remove a short piece of insulation from the inner conductor using wire strippers, tin the end of the wire with solder, and the lead is ready to be connected (see Fig.3).

This method works with some braided cables, but it can be difficult to separate the braiding into individual wires. An alternative, which can also be used with lapped cables, is to first cut back the screen so that only a few millimetres of exposed wire remain. Tin the exposed screen with solder, *trying not to overheat* and seriously melt the plastic parts of the cable.

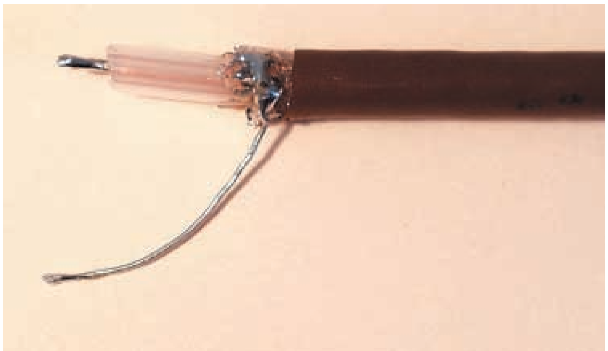


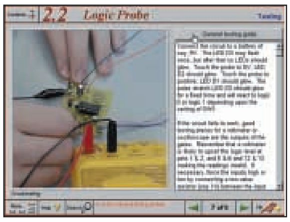
Fig.4. A coaxial cable that has been prepared for connection.

Take a short piece of tinned copper wire, wrap it around the screen, but leave 10mm or 20mm of excess wire to act as the leadout wire for the screen. Solder the wire to the screen, again taking care not to damage the cable.

Finally, remove a piece of insulation from the end of the inner conductor, and then tin this and the end of the leadout wire for the screen. This produces something like Fig.4, which is ready for connection.

ELECTRONICS CD-ROMS

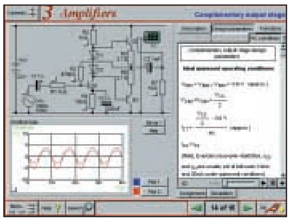
ELECTRONICS PROJECTS



Logic Probe testing

Electronic Projects is split into two main sections: **Building Electronic Projects** contains comprehensive information about the components, tools and techniques used in developing projects from initial concept through to final circuit board production. Extensive use is made of video presentations showing soldering and construction techniques. The second section contains a set of ten projects for students to build, ranging from simple sensor circuits through to power amplifiers. A shareware version of Matrix's CADPACK **schematic capture**, **circuit simulation** and **p.c.b. design** software is included.
The projects on the CD-ROM are: Logic Probe; Light, Heat and Moisture Sensor; NE555 Timer; Egg Timer; Dice Machine; Bike Alarm; Stereo Mixer; Power Amplifier; Sound Activated Switch; Reaction Tester. Full parts lists, schematics and p.c.b. layouts are included on the CD-ROM.

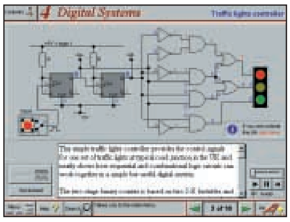
ANALOGUE ELECTRONICS



Complimentary output stage

Analogue Electronics is a complete learning resource for this most difficult branch of electronics. The CD-ROM includes a host of virtual laboratories, animations, diagrams, photographs and text as well as a SPICE electronic circuit simulator with over 50 pre-designed circuits.
Sections on the CD-ROM include: **Fundamentals** – Analogue Signals (5 sections),Transistors (4 sections), Waveshaping Circuits (6 sections). **Op.Amps** – 17 sections covering everything from Symbols and Signal Connections to Differentiators. **Amplifiers** – Single Stage Amplifiers (8 sections), Multi-stage Amplifiers (3 sections). **Filters** – Passive Filters (10 sections), Phase Shifting Networks (4 sections), Active Filters (6 sections). **Oscillators** – 6 sections from Positive Feedback to Crystal Oscillators. **Systems** – 12 sections from Audio Pre-Amplifiers to 8-Bit ADC plus a gallery showing representative p.c.b. photos.

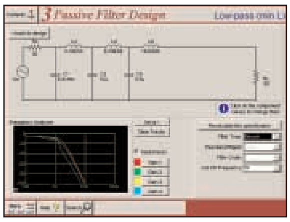
DIGITAL ELECTRONICS



Virtual laboratory – Traffic Lights

Digital Electronics builds on the knowledge of logic gates covered in *Electronic Circuits & Components* (opposite), and takes users through the subject of digital electronics up to the operation and architecture of microprocessors. The virtual laboratories allow users to operate many circuits on screen.
Covers binary and hexadecimal numbering systems, ASCII, basic logic gates, monostable action and circuits, and bistables – including JK and D-type flip-flops. Multiple gate circuits, equivalent logic functions and specialised logic functions. Introduces sequential logic including clocks and clock circuitry, counters, binary coded decimal and shift registers. A/D and D/A converters, traffic light controllers, memories and microprocessors – architecture, bus systems and their arithmetic logic units.

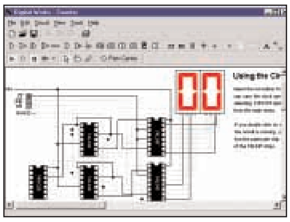
FILTERS



Filter synthesis

Filters is a complete course in designing active and passive filters that makes use of highly interactive virtual laboratories and simulations to explain how filters are designed. It is split into five chapters: **Revision** which provides underpinning knowledge required for those who need to design filters. **Filter Basics** which is a course in terminology and filter characterization, important classes of filter, filter order, filter impedance and impedance matching, and effects of different filter types. **Advanced Theory** which covers the use of filter tables, mathematics behind filter design, and an explanation of the design of active filters. **Passive Filter Design** which includes an expert system and filter synthesis tool for the design of low-pass, high-pass, band-pass, and band-stop Bessel, Butterworth and Chebyshev ladder filters. **Active Filter Design** which includes an expert system and filter synthesis tool for the design of low-pass, high-pass, band-pass, and band-stop Bessel, Butterworth and Chebyshev op.amp filters.

DIGITAL WORKS 3.0



Counter project

Digital Works Version 3.0 is a graphical design tool that enables you to construct digital logic circuits and analyze their behaviour. It is so simple to use that it will take you less than 10 minutes to make your first digital design. It is so powerful that you will never outgrow its capability.

- Software for simulating digital logic circuits
- Create your own macros – highly scalable
- Create your own circuits, components, and i.c.s
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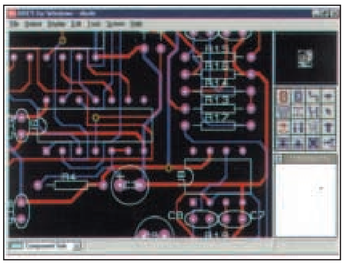
- Animation brings circuits to life
- Vast library of logic macros and 74 series i.c.s with data sheets
- Powerful tool for designing and learning

ELECTRONICS CAD PACK



PCB Layout

Electronics CADPACK allows users to design complex circuit schematics, to view circuit animations using a unique SPICE-based simulation tool, and to design printed circuit boards. CADPACK is made up of three separate software modules. (These are restricted versions of the full Labcenter software.) **ISIS Lite** which provides full schematic drawing features including full control of drawing appearance, automatic wire routing, and over 6,000 parts. **PROSPICE Lite** (integrated into ISIS Lite) which uses unique animation to show the operation of any circuit with mouse-operated switches, pots. etc. The animation is compiled using a full mixed mode SPICE simulator. **ARES Lite** PCB layout software allows professional quality PCBs to be designed and includes advanced features such as 16-layer boards, SMT components, and an autorouter operating on user generated Net Lists.

"C" FOR PICMICRO MICROCONTROLLERS

C for PICmicro Microcontrollers is designed for students and professionals who need to learn how to use C to program embedded microcontrollers. This product contains a complete course in C that makes use of a virtual C PICmicro which allows students to see code execution step-by-step. Tutorials, exercises and practical projects are included to allow students to test their C programming capabilities. Also includes a complete Integrated Development Environment, a full C compiler, Arizona Microchip's MPLAB assembler, and software that will program a PIC16F84 via the parallel printer port on your PC. (Can be used with the *PICtutor* hardware – see opposite.)
Although the course focuses on the use of the PICmicro series of microcontrollers, this product will provide a relevant background in C programming for any microcontroller.

PRICES

Prices for each of the CD-ROMs above are:

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Institutional (Schools/HE/FE/Industry)..............£99 *plus* VAT
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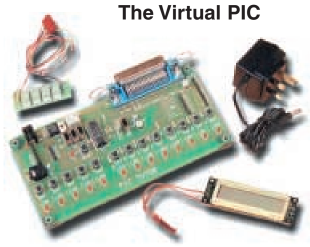
Interested in programming PIC microcontrollers? Learn with PICtutor

The Virtual PIC



Deluxe PICtutor Hardware

This highly acclaimed CD-ROM by John Becker, together with the PICtutor experimental and development board, will teach you how to use PIC microcontrollers with special emphasis on the PIC16x84 devices. The board will also act as a development test bed and programmer for future projects as your programming skills develop. This interactive presentation uses the specially developed **Virtual PIC Simulator** to show exactly what is happening as you run, or step through, a program. In this way the CD provides the easiest and best ever introduction to the subject. Nearly 40 Tutorials cover virtually every aspect of PIC programming in an easy to follow logical sequence.

HARDWARE

Whilst the CD-ROM can be used on its own, the physical demonstration provided by the **PICtutor Development Kit**, plus the ability to program and test your own PIC16x84s, really reinforces the lessons learned. The hardware will also be an invaluable development and programming tool for future work.

Two levels of PICtutor hardware are available – Standard and Deluxe. The **Standard** unit comes with a battery holder, a reduced number of switches and no displays. This version will allow users to complete 25 of the 39 Tutorials. The **Deluxe** Development Kit is supplied with a plug-top power supply (the **Export** Version has a battery holder), all switches for both PIC ports plus l.c.d. and 4-digit 7-segment l.e.d. displays. It allows users to program and control all functions and both ports of the PIC. All hardware is supplied **fully built and tested** and includes a PIC16F84.

PICtutor CD-ROM

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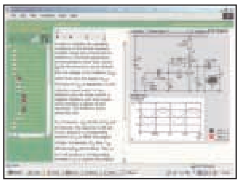

Circuit simulation screen

Provides an introduction to the principles and application of the most common types of electronic components and shows how they are used to form complete circuits. The virtual laboratories, worked examples and pre-designed circuits allow students to learn, experiment and check their understanding. Version 2 has been considerably expanded in almost every area following a review of major syllabuses (GCSE, GNVQ, A level and HNC). It also contains both European and American circuit symbols. Sections include: ***Fundamentals:*** units & multiples, electricity, electric circuits, alternating circuits. ***Passive Components:*** resistors, capacitors, inductors, transformers. ***Semiconductors:*** diodes, transistors, op.amps, logic gates. ***Passive Circuits. Active Circuits.*** *The Parts Gallery* will help students to recognise common electronic components and their corresponding symbols in circuit diagrams. Selections include: ***Components, Components Quiz, Symbols, Symbols Quiz, Circuit Technology.***

Included in the Institutional Versions are multiple choice questions, exam style questions, fault finding virtual laboratories and investigations/worksheets.

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CD-ROM ORDER FORM

B3

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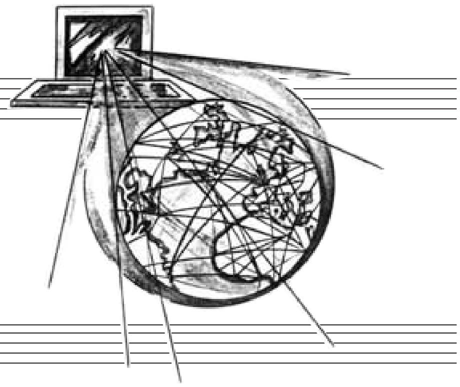
SURFING THE INTERNET



NET WORK

ALAN WINSTANLEY

WELCOME to *Net Work*, our monthly column specially written for Internet users. If you are a new reader of our magazine don't forget that you can browse through the indexes of previous issues, dating back to 1998, by visiting our web site at **http://www.epemag.wimborne.co.uk.** You can visit our popular free "Chat Zone" where you can interact with other readers using a text-based message board.

Also you can subscribe or renew your subscription using our secure order forms, and, of course, there's our online Shop (**/shopdoor.htm**) where a large range of electronics and radio books, back issues and reprints are available for purchase on-line. We also host our free source codes for our PIC projects at **ftp://ftp.epemag.wimborne.co.uk/pub/PICS** from where they can be downloaded for *free!* Lastly, don't forget that you can buy *EPE* and download it to your computer for just $9.99(US) for 12 issues (about £7.20) from our *EPE Online* web site at **www.epemag.com**.

DVD Resources

Very recently I trundled into my local Maplin store in search of a DVD-ROM drive for my PC, only to be told that they have all been discontinued . . . !

In the UK the DVD player was *the* consumer product to get at Christmas 2001 and prices for DVD players are still falling. Adding a DVD player (DVD-ROM) is a very worthwhile and simple upgrade for PC users, and 16-speed DVD ROM drives are available for only £50 from computer stores. Some magazine cover disks are available in DVD format and they include more video footage and content than can ever be squeezed onto a CD-ROM. This month's *Net Work* offers web users a few pointers to DVD (Digital Versatile Disk) resources available out there in cyberspace.

If you're thinking of buying a PC DVD-ROM drive, it is always worth searching the Internet to see what's on offer, so query some shopping carts to compare prices. You will probably have a far wider choice than any computer store can offer, plus you get an opportunity to do some homework first.

A good place to start is the official Internet DVD FAQ for the **rec.video.dvd** Usenet newsgroup at **www.dvddemystified.com/dvdfaq.html** which is extremely comprehensive. A DVD Frequently Asked Questions page is at **http://faq.inmatrix.com** where there are some pointers available to those who are new to DVDs, including information on region codes.

To play DVD movie footage you will need some decoder hardware and software as well. Windows 95/98 *cannot* play DVDs *directly* (both Windows ME and Windows XP can), and Apple users probably have an easier life in this respect. Before you do anything, check DVD compatibility in your operating system first (look around Windows Media Player especially) as you may be able to fetch free upgrades or patches over the Internet: check **www.microsoft.com** as required.

Free But Not Easy

A search for freeware DVD software players produced very mixed results. You can try a freeware player at **www.maximus-dvd.com** or search Google for alternatives. However, the general feeling seems to be that commercial software produces better and more consistent performance. Earlier software packages or bundled programs sometimes had compatibility problems so a current software product is probably the best answer.

A very popular DVD player is Cyberlink's PowerDVD 4 which is available for download and direct purchase from **www.gocyberlink.com**. Version 4 installed and worked perfectly on my own system, unlike an earlier version, and it is also Windows XP compatible if you don't get on with Windows Media Player. It costs $49.95 for the download edition.

Be aware that you can change the region code no more than five times in PowerDVD after which the software will lock you into your fifth selection. It is fully skinnable so you can change its look and feel; a "skin" kit is available online, as are PDFs showing you how to compose your own skins using your own graphics package. (I'm working on a stripboard version!)

More details are at **www.dvdonet.com** from where more skins can also be downloaded (those intended for V3 also ran on the latest V4). If you have a TV card installed as well, consider Cyberlink's PowerVCR 2 which includes PowerDVD 3 and turns your system into a complete video recorder – provided you have the hard disk space! This and more can be downloaded from Cyberlink's web site.

Other DVD resources include **www.digital-digest.com/dvd/downloads/playback.html** where there are some applications available for Linux and Apple users. Several DVD stores are online, including Amazon (**www.amazon.co.uk**) and the BBC (**www.bbcshop.com**). Time to break out The Matrix on DVD again, to see if I understand it!

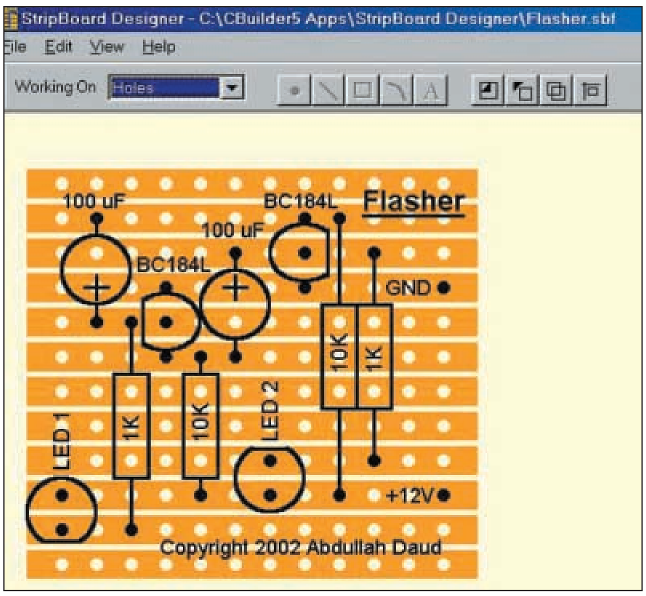
Stripboard Designer

When developing circuits it is often a good idea to prototype them on stripboard if possible, which gives you the flexibility needed to modify the circuit design. Many hobbyists crave for a PC software package that will assist in designing the component and copper track layouts on-screen.

Several years ago a package called "Stripboard Magic" made a brief appearance but there has been nothing available since then. A simple stripboard layout program is now offered by Abdullah Daud who emails me to say that a free demo version can be downloaded from his web site at **www.geocities.com/stripboarddesigner**. It has no schematic capture function but may still help to design the component layout.

The simple program includes the ability to draw shapes, place wires or make holes. Also included is a small component library to get you started. The program is in its early days, and I noted the odd glitch placing component shapes, but there's no beating the principle of trying shareware first so why not download the trial and check it out for yourself. The likely cost to buy will be $25.00.

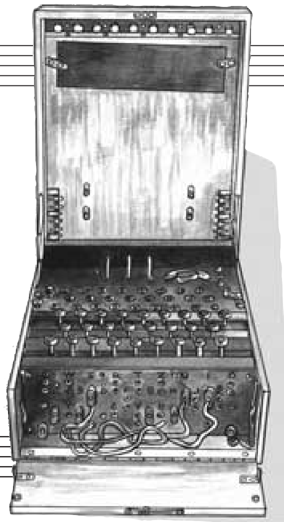
You can email the author at **alan@epemag.demon.co.uk**.



Screenshot of StripBoard Designer Version 1.1.

Constructional Project

PIC MINI-ENIGMA



NICK DOSSIS

Share encrypted messages with your friends – true Spymaster entertainment!

PIC Mini-Enigma was born out of the author's interest in both encryption techniques and PIC microcontrollers. The initial idea was to create a PIC-based unit that would enable the user to type in a brief text message, which can then be encrypted at the press of a button.

By the same token, if the encrypted message was typed into the unit it could be decoded into the original text message. This would enable two people to send secret messages to each other and be safe in the knowledge that the text would be very difficult to decipher without using the unit.

The design also has the unique capability of allowing the user to download a message to the data EEPROM (electrically erasable programmable read only memory) of a second PIC, housed in a tiny box, such as a matchbox. The information from the "matchbox" memory can then be retrieved by the other person at a later time by using their own Mini-Enigma unit.

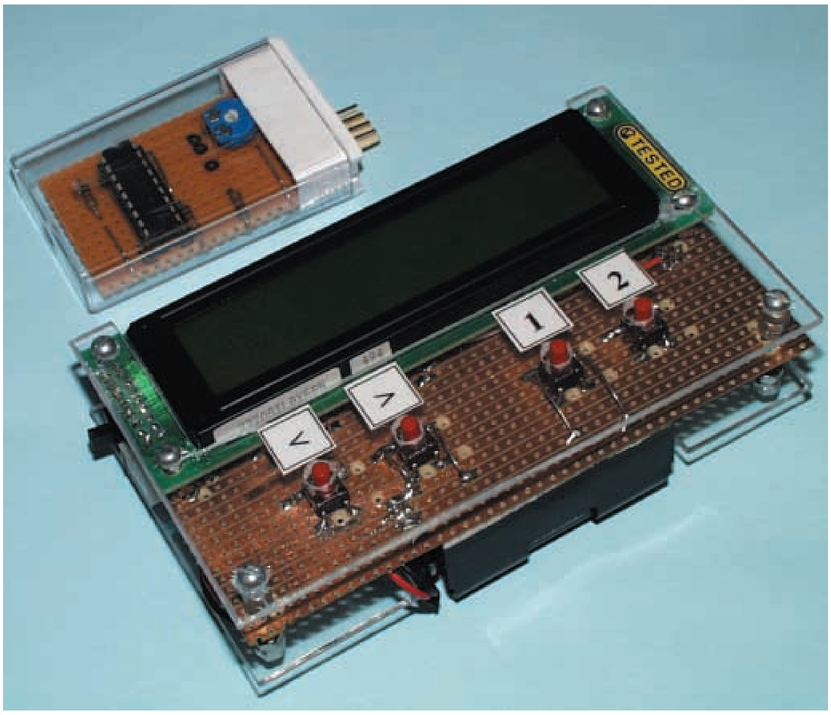
DATA SWAPPING

At the time that the idea was conceived, the author was playing around with the PIC16F84 and an alphanumeric liquid crystal display (l.c.d.). After connecting the l.c.d. to the PIC and programming it to show a line of text, it was discovered that some of the characters were being displayed incorrectly.

Further investigation showed that two of the data lines from the PIC to the l.c.d. had inadvertently been swapped over. It was this error which had caused the incorrect text to appear on the screen.

This gave rise to thoughts about the way the l.c.d. requires an ASCII-coded data byte to be sent to it to cause the required letter to be displayed. Naturally, by suitably altering the order of the bits that make up the byte, a different character could be displayed instead.

This seemed to be an ideal way of encrypting a line of text within the PIC, and is the basis of the program that controls this project.



ENIGMATIC

The original Enigma unit was a coding machine used in the Second World War by the Germans. It was a very complex machine, which amongst other features contained interchangeable connecting wires and rows of scramblers, which changed their position every time a letter was encoded.

This method ensured that there was hardly any duplication of encoded text because the letters were altered automatically after every encryption. It took the British several years to crack Enigma's coding technique.

The Mini-Enigma described here does not profess to be the miniature equivalent of the original machine. However, the encryption technique uses a coding method that alters the way individual letters are encrypted. To the untrained eye, it is very difficult to crack the code.

ENCRYPTION METHOD

The method of encryption, which is documented in the assembly program, utilises a codeword set by the user and which is stored in the Enigma's data EEPROM. This means that the way in which the message is encrypted can be altered and so deciphering the text will only be possible by using the same codeword that was used to encrypt the original message. The codeword can be up to eight digits long.

First, regard alphabet letters A to Z as numerical values from 1 to 26. Then, for example, if the codeword is set as ABCD this would have an equivalent numerical value of 1234 (see Table 1). Now suppose the message BYEBYE needs to be encrypted, the process is as follows:

Since the codeword is ABCD, its first letter, A, has an allocated value of 1. This is added to the allocated value of the first letter of the message, B, i.e. B + 1 = C. C thus becomes the code letter for B at this point of the encryption.

The second letter of the message has the value 2 added to it as it is the alphabet value of second character of the combination. This converts the letter Y into letter A.

This procedure repeats itself until the last letter of the codeword has been reached. The process then begins again by starting back at the first number of the codeword.

In this fashion, the message BYEBYE becomes encrypted as CAHFZG. See Example 1.

Example 1:

Message	B	Y	E	B	Y	E
Codeword	A	B	C	D	A	B
	1	2	3	4	1	2
Encryption	C	A	H	F	Z	G

It can clearly be seen that the encryption method is very secure because although the original message contains two identical words, the encrypted version does not give any clues that this is the case. Remember also that the Mini-Enigma can be programmed to accept an 8-digit codeword comprising any of the 26 letters of the alphabet, therefore making the possibility of somebody decoding the encrypted message even harder.

It should be noted that the encrypted message is totally dependent on the codeword. Mini-Enigma units which have been programmed with different codewords will encrypt the message in a totally different way. An example of this is outlined in Example 2 when the codeword is changed to BCDE.

Example 2:

Message	B	Y	E	B	Y	E
Codeword	B	C	D	E	B	C
	2	3	4	5	2	3
Encryption	D	B	I	G	A	H

The basis of the software is to either add or subtract the individual codeword values to the ASCII code which is sent to the l.c.d. Coding the text adds the value and decoding the text subtracts the value.

The problem encountered when using this method was that ASCII codes 27 to 38 are not letters and therefore there had to be software routines incorporated to bypass these values when an addition or subtraction occurred.

DATA TRANSFER

As mentioned earlier, the unit also includes the facility for downloading an encrypted message into the data EEPROM of a second PIC, housed in a separate box, from hereon referred to as the "Matchbox" unit.

The data transfer uses a unique protocol which was specifically designed for this project and allows the encrypted ASCII code of each character to be transmitted serially from the unit to the PIC inside the Matchbox.

The connections between the Mini-Enigma unit and the Matchbox are via a 4-pin connector. These connections comprise the +5V and 0V supply, plus data and clock lines.

For all intents and purposes, the data is transmitted over two wires, data and clock. Because the Matchbox is controlling the data transfer and its clock is running at a slower speed than the Mini-Enigma, this ensures that the data transfer runs without errors. There is specific handshaking associated with the protocol, which is written into the software of both units.

When the Matchbox is first energised, it waits for either a "load" or "save" instruction from the Mini-Enigma:

Lines:	Clock	Data
Load:	0	1
Save:	1	0

Table 1 – ASCII and Codeword Values used in the Enigma Unit

	Letter	ASCII Code	Codeword value		Letter
1	A	0100 0001	0000 0001	1	A
2	B	0100 0010	0000 0010	2	B
3	C	0100 0011	0000 0011	3	C
4	D	0100 0100	0000 0100	4	D
5	E	0100 0101	0000 0101	5	E
6	F	0100 0110	0000 0110	6	F
7	G	0100 0111	0000 0111	7	G
8	H	0100 1000	0000 1000	8	H
9	I	0100 1001	0000 1001	9	I
10	J	0100 1010	0000 0010	2	J
11	K	0100 1011	0000 0011	3	K
12	L	0100 1100	0000 0100	4	L
13	M	0100 1101	0000 0101	5	M
14	N	0100 1110	0000 0110	6	N
15	O	0100 1111	0000 0111	7	O
16	P	0101 0000	0000 0000	0	P
17	Q	0101 0001	0000 0001	1	Q
18	R	0101 0010	0000 0010	2	R
19	S	0101 0011	0000 0011	3	S
20	T	0101 0100	0000 0100	4	T
21	U	0101 0101	0000 0101	5	U
22	V	0101 0110	0000 0110	6	V
23	W	0101 0111	0000 0111	7	W
24	X	0101 1000	0000 1000	8	X
25	Y	0101 1001	0000 1001	9	Y
26	Z	0101 1010	0000 0010	2	Z

Once it has received its instruction, the Matchbox program is then diverted to the relevant routine. The basis of the protocol is shown later in Table 2.

ENIGMA CIRCUIT

The circuit diagram for the Mini-Enigma is shown in Fig.1.

The heart of the system is the PIC16F84 microcontroller, IC2. Its oscillator is run in *RC* (resistor-capacitor) mode, with potentiometer VR2 presetting the speed. The capacitance is that inherent in the PIC itself and a separate capacitor is not used.

Even though communication between the Mini-Enigma and the additional Matchbox memory uses serial data transfer, software routines ensure that the exact timing is not too critical. Consequently, crystal control is not needed.

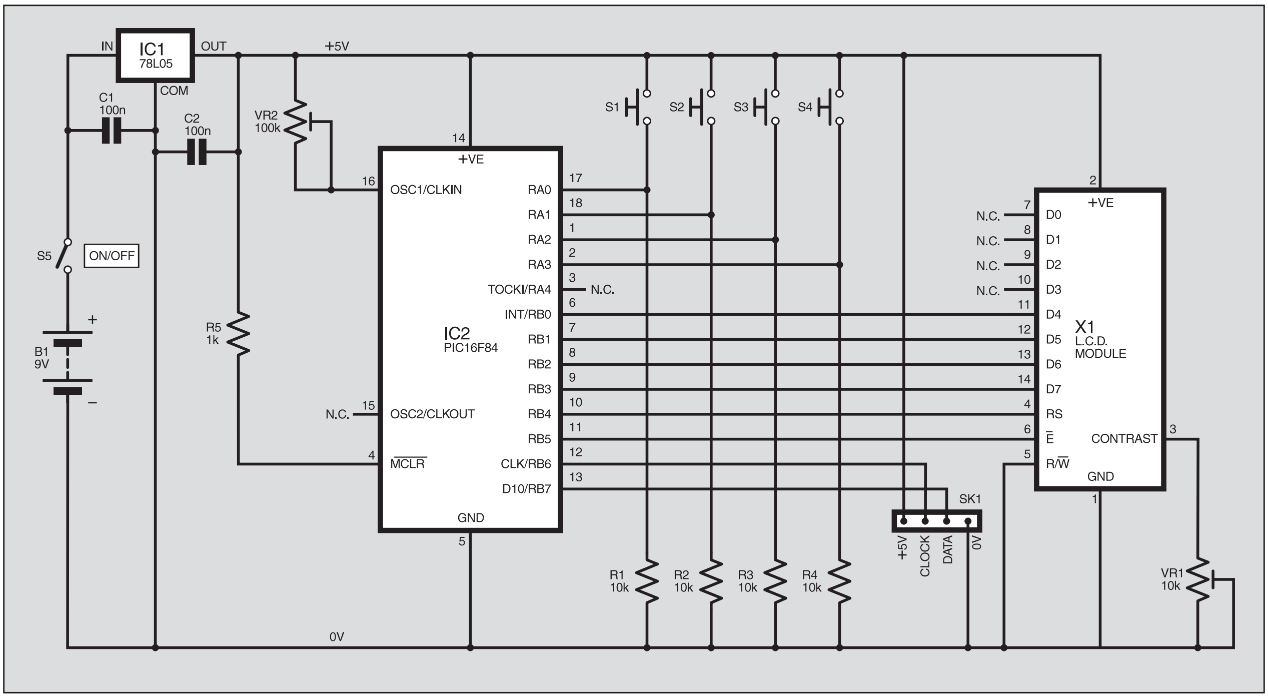


Fig.1. Circuit diagram for the main aspect of the Mini-Enigma unit.

The PIC is connected via port pins RB0 to RB5 to a 20-character × 2-line alphanumeric liquid crystal display (l.c.d.), X1. This is controlled in standard 4-bit mode. Preset potentiometer VR1 controls the screen contrast.

PIC port pins RA0 to RA3 are held normally-low by resistors R1 to R4 and are taken high whenever the relevant pushbutton switch, S1 to S4, is pressed.

Communication with the Matchbox memory unit is via clock pin RB6 and data pin RB7.

The circuit is powered by a 9V PP3 battery, via on/off switch S5. Regulator IC1 reduces the supply to +5V, as required by the PIC and l.c.d. Capacitors C1 and C2 decouple and smooth the supply.

MATCHBOX MEMORY CIRCUIT

The circuit diagram for the additional Matchbox memory unit is shown in Fig.2. It consists primarily of another PIC16F84 microcontroller, IC3. It does not require a battery because it receives its power from the host Mini-Enigma via the 4-way connector.

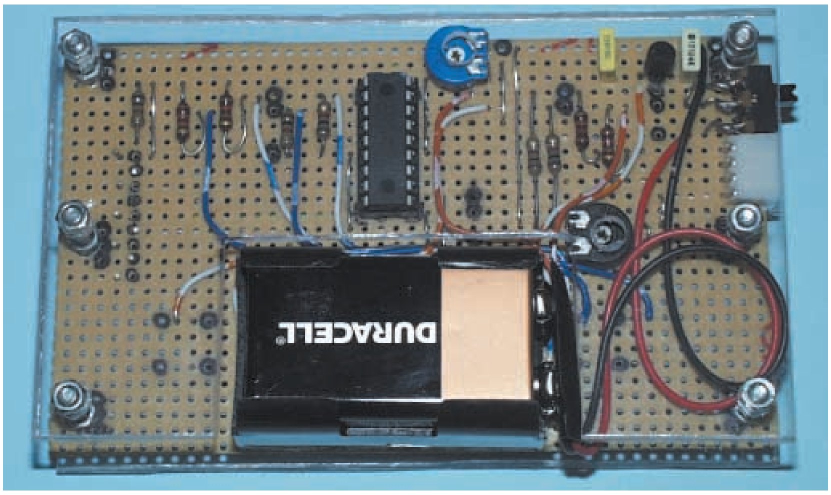
The clock and data lines are held normally-low via resistors R6 and R7, but are under control of the Mini-Enigma when the two units are connected.

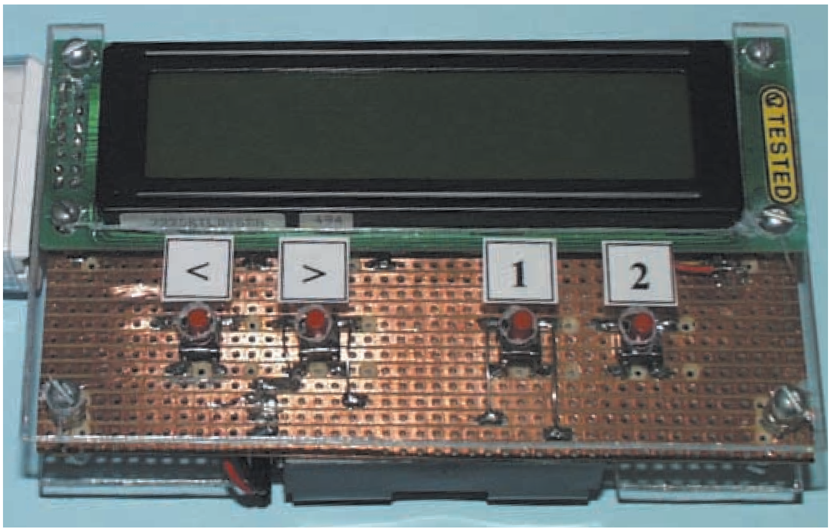
This PIC runs at a slower speed than the one in the Mini-Enigma, as set by capacitor C3 and variable by preset VR3.

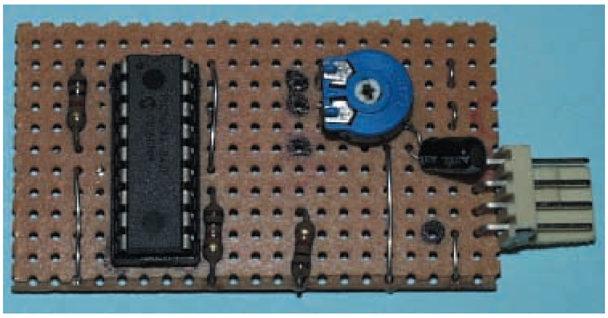
ENIGMA BOARD

The component layout and track cutting details for the Mini-Enigma and its Matchbox unit are shown in Fig.3. Ensure that all the track cuts are made. Use 22s.w.g. plastic covered solid copper wire for the link connections. Dual-in-line (d.i.l.) sockets should be used for the PICs.

Referring to Fig.3a, solder the components onto the stripboard in the following order: d.i.l. socket, links, resistors, 1mm terminal pins, voltage regulator, capacitors, on/off switch S5, edge connector, pushbutton switches S1 to S4, and the battery lead.







Note that the published Mini-Enigma has fewer resistors than shown in the top photograph.

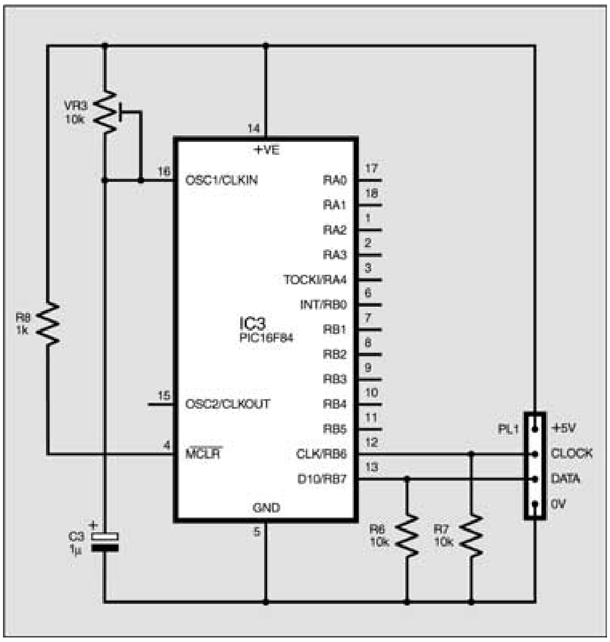


Fig.2. Circuit diagram for the "Matchbox" unit.

Note that switches S1 to S4 plus four additional link wires are soldered on the track-side of the stripboard.

Once the basic stripboard assembly is complete, use double-sided tape to stick the battery holder onto the back of the stripboard. Then connect the longer wires that route around the battery.

Do not wire-up the l.c.d. or plug in the PIC yet.

Check that the component layout and solder joints are sound. If at any stage of testing the results are not correct, disconnect the battery immediately. Re-check the component positions and solder joints, and then restart the checks.

Apply power to the stripboard and check that +5V appears at various components according to the circuit diagram. If all is well following this initial power check, disconnect the battery, connect the l.c.d., making sure that there is enough slack in the cable to assemble the unit, and then insert the preprogrammed PIC (assembly file E2.ASM). With power applied again, do another check that 5V is still present as required.

Check that the PIC's input pins 1, 2, 17 and 18 are normally low, and that pressing the pushbutton switches makes the relevant pins go high.

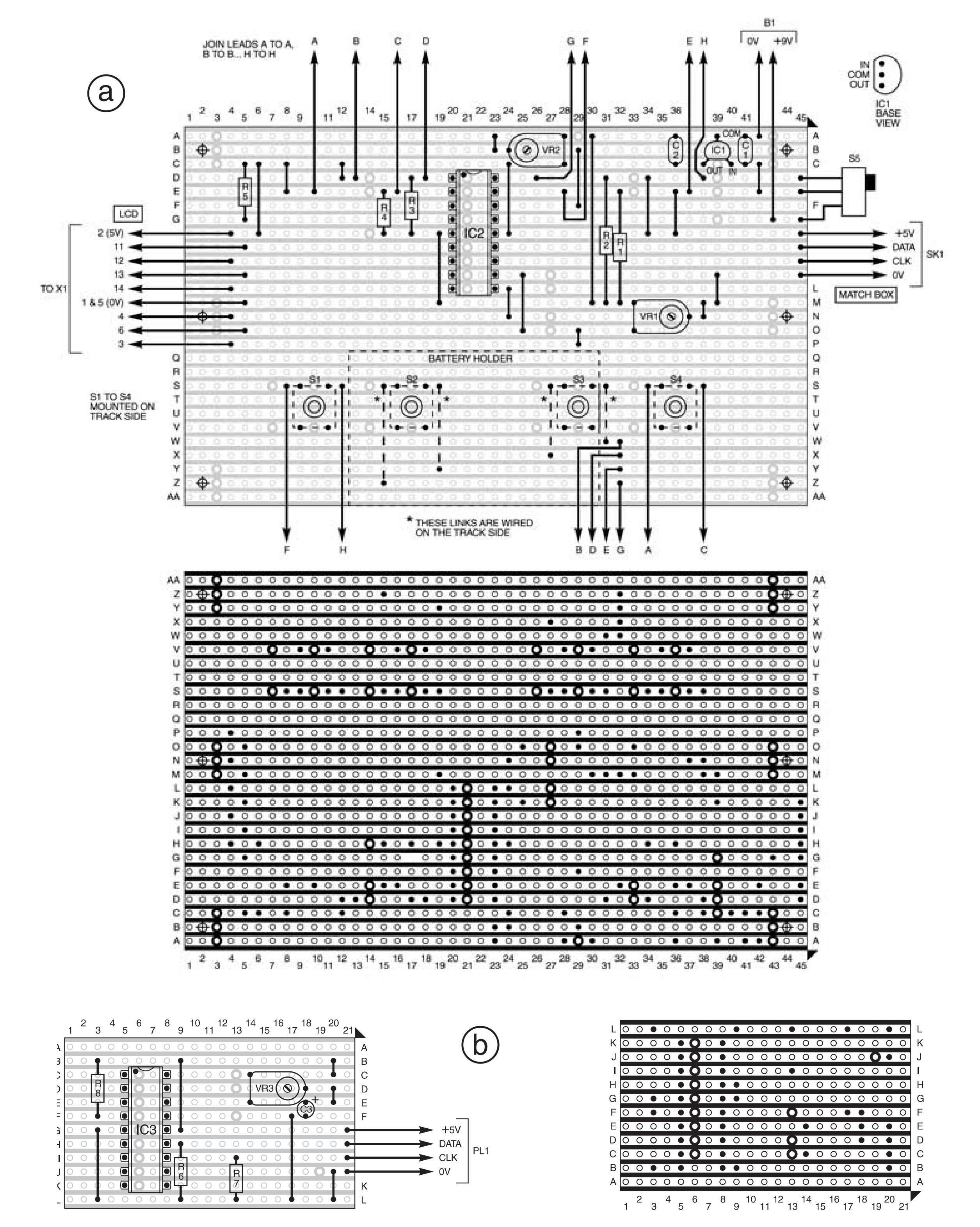


Fig.3. Stripboard component layouts and details of underside copper track breaks for the Mini-Enigma (a) and Matchbox unit (b). Note that in Fig.3a switches S1 to S4 and four link wires are mounted on the trackside. The lettered links should be made using insulated solid hook-up wire, linking like-lettered points (i.e. A to A, B to B, etc.).

Adjust the l.c.d. contrast control, VR1, until the start-up screen is seen clearly. The screen display modes are discussed later.

Adjust the clock rate control, VR2, until the unit works at a satisfactory speed for pushswitch presses. In the prototype, this was with VR2 set for a resistance of about 10kΩ to 15kΩ.

MATCHBOX MEMORY BOARD

Referring to Fig.3b, assemble the Matchbox memory board.

The small piece of stripboard used was intended to be small enough to fit snugly inside a standard size matchbox. A matchbox was felt to be suitable because it is inconspicuous and conceals the electronics, an ideal cover for the budding spy!

However, the author found that the stripboard is also the ideal size to fit inside an empty Tic-Tac box, the clear box matching the theme of the Enigma unit. So this is the enclosure that was used in the prototype.

COMPONENTS

Resistors
R1 to R4, R6, R7 10k (6 off)
R5, R8 1k (2 off)
All 0·6W metal film

See SHOP TALK page

Capacitors
C1 to C2 100n ceramic, 0·2in pitch
C3 1µ radial elect. 16V

Potentiometers
VR1, VR3 10k min. horiz. skeleton preset (2 off)
VR2 100k min. horiz. skeleton preset

Semiconductors
IC1 78L05 +5V 100mA voltage regulator
IC2, IC3 PIC16F84 microcontroller, each separately pre-programmed (2 off)

Miscellaneous
S1 to S4 push-to-make switch, p.c.b. mounting 0·2in x 0·3in pitch, 6mm to 7mm "push actuator" (see text) (4 off)
S5 min s.p.c.o. slide switch, p.c.b. mounting
SK1 4-way edge connector, female, p.c.b. mounting
PL1 4-way edge connector, male, p.c.b. mounting
X1 2-line x 20-characters per line alphanumeric l.c.d., with standard HD44780 controller

Stripboard, 0·1in pitch, 45 holes x 27 strips; stripboard, 0·1in pitch, 21 holes x 12 strips; 18-pin d.i.l. socket (2 off); 25mm 6BA nuts and bolts (see text); clear acrylic perspex sheet (2mm x 117mm x 70mm) (2 off); 9V PP3 battery and connecting clip; Tic-Tac box (see text).
Software: Available as stated in *Shoptalk*.

Approx. Cost Guidance Only **£25** *excluding case*

The 4-way edge connector is fitted to the stripboard so that it protrudes through the hole in the Tic-Tac box, although the hole needs to be made a little larger to stop the box fouling on the Enigma's on/off switch when the two units are plugged together.

Solder components onto stripboard in order of d.i.l. socket, link wires, resistors and edge connector. Do not insert the PIC yet. Check the assembly for errors.

Adjust VR3 (PIC clock rate) for an effective resistance of about 3·1kΩ to 3·8kΩ.

Before inserting the PIC, plug the unit into the Enigma's connector (space limitations may make it necessary to switch on the Enigma first). Check that +5V is present as indicated in the circuit diagram.

If the checks are satisfactory, disconnect the unit from the Enigma and insert the second preprogrammed PIC (assembly file EEPROM.ASM).

ENCLOSURE

The author wanted the Mini-Enigma to look a little bit different from the usual constructional projects, but did not find the standard types of enclosure to be suitable. Consequently, the prototype was built using two pieces of 2mm thick clear acrylic perspex which form the "bread" of the stripboard sandwich.

Referring to Fig.4, cut the two pieces of perspex to the same size. Cut the slots and drill to match the mounting holes in the stripboard and l.c.d. Drill additional holes in the front piece of perspex to allow the pushbutton switches (S1 to S4) to protrude through. The whole unit is transparent allowing the electronics to be visible.

Cut a space in the back piece of perspex to allow access to the PP3 battery without having to take the unit to pieces. The 4-way female serial connector is mounted on the side of the stripboard and is positioned so that the Matchbox memory unit is able to be plugged into the Mini-Enigma.

The on/off slide switch, S5, is also mounted at the side.

The whole sandwich can now be combined into one unit, using 6BA bolts and with additional nuts to create spacers between the l.c.d. and the stripboard. Labels can now be secured above the

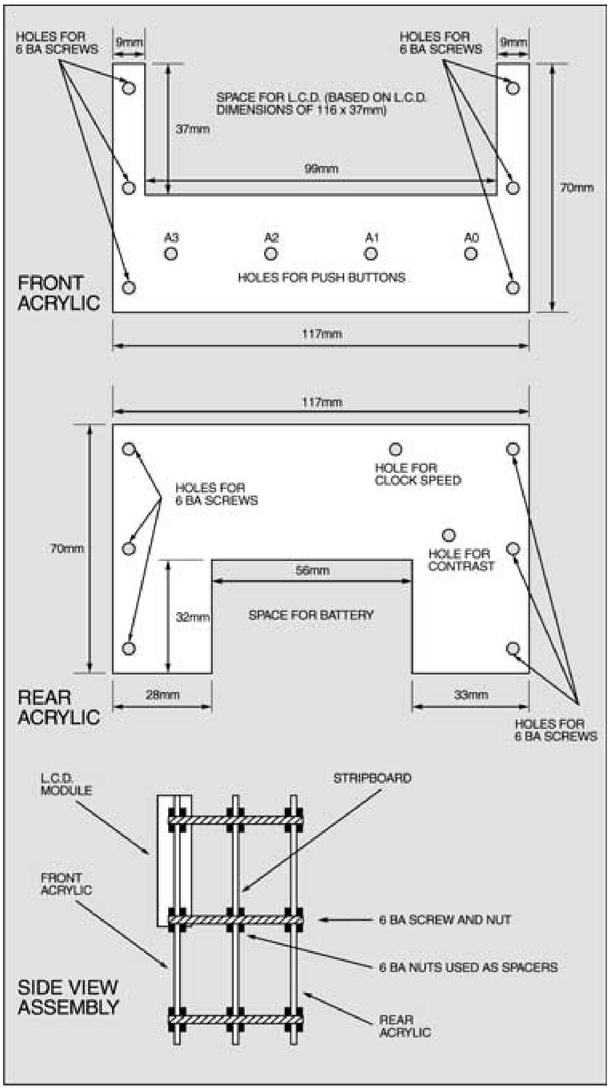
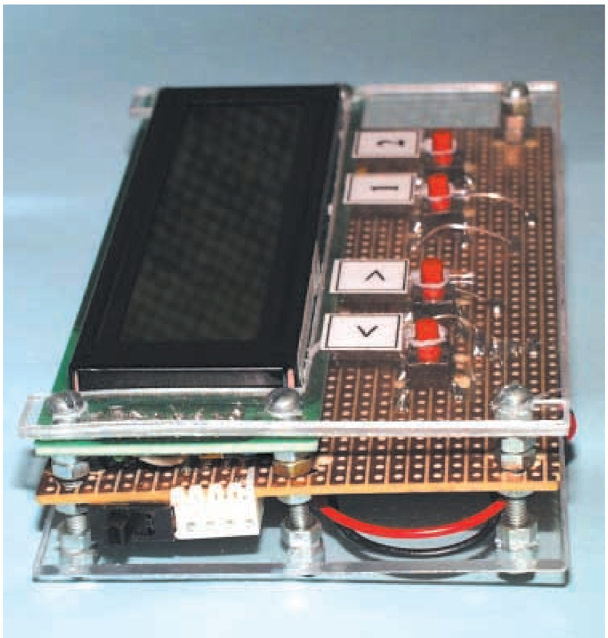


Fig.4. Construction details of the perspex plates and how they "sandwich" the Mini-Enigma stripboard.



End view of the assembled Mini-Enigma "sandwich".

pushswitches, showing from left to right the legends "<", ">", "1", "2" (see photos).

CODE CHECKS

When assembly and checking are complete, insert the pre-programmed PICs, follow the operating instructions discussed presently and check that data can be interchanged between units.

First code a line of text on the main unit and then save it into the Matchbox. Switch everything off and then attempt to load the data back into the Enigma. If problems are experienced when transferring data, adjust the speed of the Matchbox using preset VR3 and try again.

From experience there is quite a narrow "window" for the resistance value, found to be around 3kΩ to 4kΩ. It should be noted, however, that once data transfer has been achieved successfully VR3 should never need to be adjusted again.

OPERATING TECHNIQUE

When the Enigma is first switched on, the Start-up screen appears:

Start-up screen.

Pressing any key changes the display to show Screen 1, in which instructions are given on the lower line:

Pressing switch "<" or ">" causes the current letter of the codeword or message you wish to record, as shown on the top line and underlined, to rotate down ("<") or up (">") through the alphabet. When the required letter is reached, press switch "1" (Enter) to select it. The underline then moves to the next character cell and the required letter can again be reached by using "<" or ">", and selected by "1".

Screen 1, for entering a message or codeword.

If a wrong letter is entered this can be rectified by again pressing switch "1" before pressing "<" or ">". This deletes the last letter entered.

A message of up to 40 characters can be entered onto the top line if required. Once 20 characters have been entered, both lines of the screen rotate to the left so that the text can be followed on the screen, with the instructions being duplicated so that they can be seen at all times.

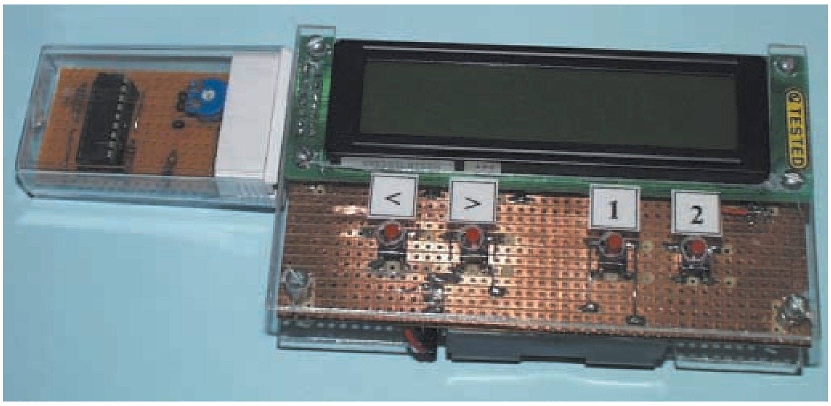
Once the codeword or message has been completed switch "2" (Next) can be pressed, to take you to Screen 2:

Screen 2, function choice.

Table 2 – Data Save and Load Routines

Step	*Mini-Enigma*	*Matchbox Unit*
1.		Wait for Save signal
2.	Send Save signal	
3.		Accept Save signal
4.		Send high clock signal
5.	Receive high clock signal	
6.	Send data bit X	
7.		Accept bit X
8.	Wait for low clock signal	
9.		Process data and send low clock signal
10	Receive low clock signal	
11.		Loop back to step 4 until 8-bit word is complete
12.		Store 8-bit word in EEPROM memory
13	Loop back to step 5 until 8-bit word is complete	

Step	*Mini-Enigma*	*Matchbox Unit*
1.		Wait for Load signal
2.	Send Load signal	
3.		Accept Load signal
4.	Pause	
5.		Retrieve EEPROM memory
6.	Wait for high clock signal	
7.		Send high clock signal and data bit X
8.	Accept high clock signal and data bit X	
9.		Send low clock signal
10.	Accept low clock signal	
11.		Loop back to step 5 until 8-bit word is complete
12.	Loop back to step 6 until 8-bit word is complete	
13.	Store data in indirect file memory	



Matchbox unit plugged into Mini-Enigma.

If the unit has been powered up for the first time, or if the codeword is to be altered, press switch "2" (now indicated as Match Box). This will take you to Screen 3:

Screen 3. Second choice of functions.

Pressing "1" (codeword) then shows a screen display such as the following:

Screen 4. Choice of codeword saving or retention.

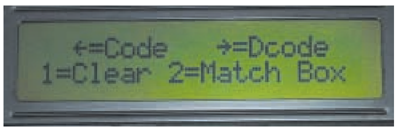
The top line shows the new codeword just created via Screen 1 (e.g. ABCD). The second line shows the current codeword already stored in the Enigma's EEPROM (e.g. ZYA). Pressing the "<" switch stores the top line codeword into the EEPROM as the new codeword, overwriting the existing one. However, pressing the ">" switch instead causes the new codeword to be ignored, while retaining the existing one.

In either instance, the switch press causes Screen 1 to be displayed again.

A text message can then be "keyed in" using the "<", ">" and "1" keys, e.g.:

Screen 1 again, for message entering.

Once complete, pressing switch "2" once more displays Screen 2:



Screen 2 again, this time for choice of message function

If the text entered is a normal message and you wish to encrypt it, press “<”. If the text entered is encrypted and you wish to discover the original message, press “>”. If you wish to abort, pressing “1” clears the memory and returns to Screen 1, allowing you to enter some new text.

If either the “<” or “>” switches are pressed, the screen then shows two lines of text, the top line is the original text which was entered (either manually or via the matchbox), and the bottom line is the coded or decoded version.

An original message (top) and its encryption (lower).

Pressing the “<” or “>” switches while viewing the text shifts the screen left or right. This is particularly useful when the message contains more than 20 letters.

Once the viewing of text has been finished, press “2”, which returns the display to Screen 2. This causes the coded or decoded text (as just shown on line 2) to be stored in the Enigma’s memory. Coding or decoding can be carried out again if wished. Pressing “1” clears the memory and returns to Screen 1.

TRANSFERRING DATA

A 40-digit encrypted message can be “saved” to a Matchbox memory unit for future retrieval. The procedure for this is as follows:

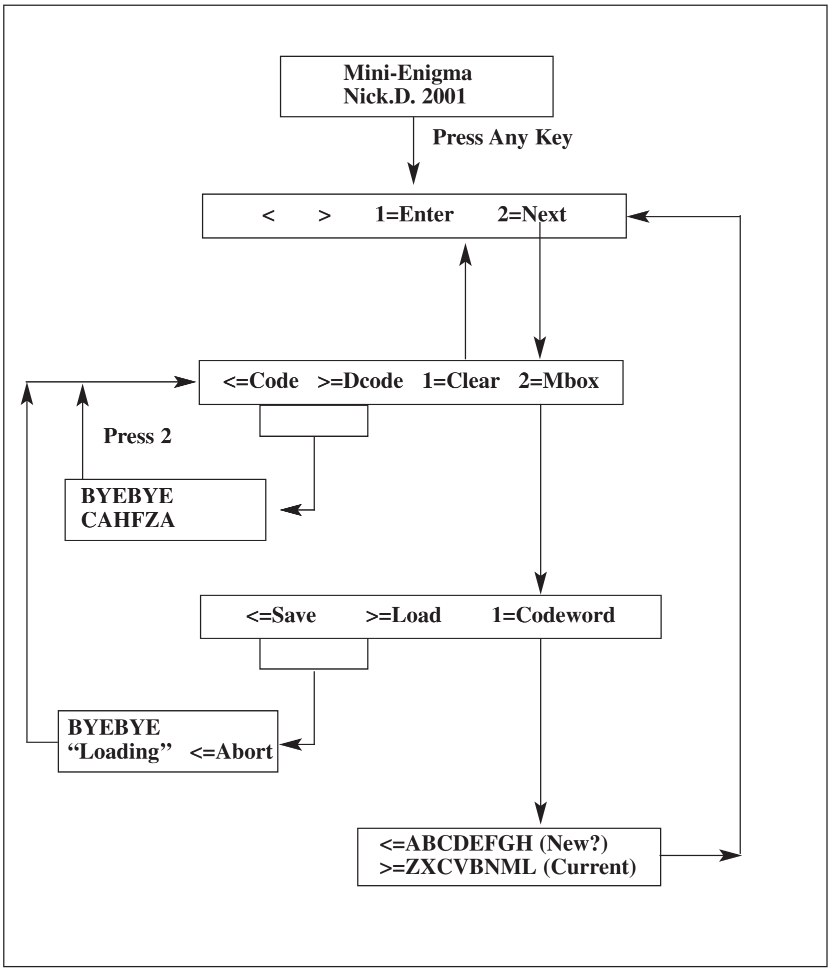
Type in the required message and proceed to Screen 2 to encrypt the message. Once the encrypted message is on the screen, press “2” to return to Screen 2. As said earlier, this has the effect of storing the encrypted message in the Enigma’s memory. Plug the Matchbox memory into Enigma and then press “2” again, which then produces the following message on Screen 3.

Screen 3 again, offering choice of data transfer function.

Pressing the appropriate key begins the data transfer either to (“<” save) or from (“>” load) the Matchbox memory. The following screen appears just prior to loading commencing:

Screen immediately prior to loading a Matchbox message.

When loading or saving data, each letter transferred appears on the screen starting on line 1. If the message is shorter than 40 characters then the data transfer finishes once the final letter of the message has been received. The program does this by looking for ASCII code 128 (binary 1000000). If this character is recognised as being transferred then both programs end the data transfer.



The logic flow chart for using Mini-Enigma.

The data transfer takes about 100 seconds for all 40 characters, and once complete the l.c.d. reverts back to Screen 2. This allows the user either to clear the Enigma’s memory and start again, or to decode the received message. Once the data transfer has been completed, the Matchbox unit can either be unplugged and passed onto a friend, or it can be left plugged into the Enigma where another load or save can be performed.

If problems are experienced when loading or saving to the memory unit, pressing the “<” key aborts the transfer. If for some reason problems still exist, remove the memory unit and re-boot the Mini-Enigma unit by switching off and then switching back on.

Be aware that sometimes the first bit (bit 7) of the first character transferred becomes corrupted (i.e. it is made high instead of low), the software in the Enigma clears bit 7 of all characters before it shows them on the l.c.d. to eliminate this problem.

An encrypted message from the Matchbox unit (top and its decoded meaning (lower).

A late model of the Enigma, circa 1947.

ACKNOWLEDGEMENTS

John Becker, *PIC Tutorial* series March to May ’98. The author says he did not start reading the *Tutorial* until Dec ’00, but by Feb ’01 he had written the basics of the code for this project.

Simon Singh, *The Codebook*, published by The 4th Estate, which gives excellent descriptions of many different encryption techniques and includes the history of the original Enigma unit.

Jack Chisnall, the author’s late Grandfather who bought him his first copy of *Everyday Electronics* in the mid 1970’s.

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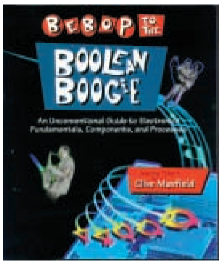

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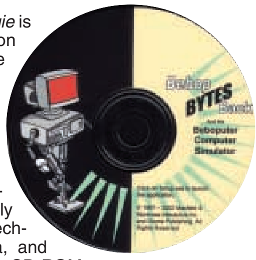

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